THE RELATION OF CHEMISTRY TO THE PROGRESS OF AGRICULTURE.

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INTRODUCTION.

This paper will be devoted, in so far as possible, to the progress of agriculture in the United States during the nineteenth century. Inasmuch, however, as the factors of a chemical nature influencing agriculture are largely made up of forces emanating from other countries, it will not be possible to separate entirely the discoveries made in foreign countries from those made in the United States.

In order to keep the paper within suitable limits for the Yearbook, no attempt will be made to trace the progress of agriculture in its relation to chemistry from year to year, and the subject will be considered from three principal points of view only, namely:

(1) The relation of chemistry to agriculture at the beginning of the century.

(2) The impetus given to scientific agriculture in its relation to chemistry by the discoveries of Liebig, Gilbert, Boussingault, and other workers, which began to produce effects about the middle of the century.

(3) A résumé of the relations of chemistry to agriculture up to and at the present time, with a brief reference to the principal methods whereby chemical research has been made useful to practical agriculture.

The above is not only a convenient division of the whole subject for the purpose of discussion, but it also portrays the three principal epochs in the relations of chemistry to agriculture for the century.

From a chemical point of view, the knowledge of scientific agriculture, as it existed at the beginning of the century, was practically all that was known until near its middle point, when the work and researches of the distinguished men mentioned and others associated with them were beginning to have practical application. From this point onward to the present time the influence of chemical research on progressive agriculture has been more and more felt through certain lines of investigation, until it has brought the science of agriculture to its present condition.

In a statement of that part of the subject relating to chemistry and agriculture at the beginning of the century it will be sufficient to
refer to the standard works which were published at or about that time, and which are still accessible in our libraries. The literature of the middle of the century is so voluminous that only a brief reference to it can be given. In a discussion of the third division of the subject, or a review of the relations of chemistry to agriculture to the present time, etc., the progress of agriculture under the influence of chemical studies and researches will be considered in the briefest possible manner in several typical lines, among which may be mentioned: First, the teaching of agriculture in schools, colleges, and universities; second, the agricultural colleges and experiment stations; third, the agricultural press; and, fourth, the chemical studies conducted under the auspices of the Department of Agriculture, including those collected in the reports of the Patent Office relating to agriculture, which began to issue shortly before the middle of the century.

The attitude of chemical science toward agriculture at the beginning of the century may be presented under three divisions:

(a) The knowledge which was possessed concerning the nature of the soil and its relation to plant growth.

(b) The knowledge possessed concerning the nature of manures and the manner in which they increase the yield of crops.

(c) The prevalent ideas concerning the composition of agricultural crops in relation to their demands upon the soil and upon fertilizers.

**STATUS OF AGRICULTURAL CHEMISTRY AT THE BEGINNING OF THE CENTURY.**

Under this head will be given, first, a summary of the state of knowledge at or about the beginning of the century in regard to the above several points, and second, some brief observations of a general nature on the soundness or unsoundness of the views then held.

Fortunately for the purpose of this part of the paper, the relations of chemistry to agriculture at the beginning of the century have been accurately and faithfully portrayed in works appearing near that period and still accessible. Among these may be mentioned:


"The Spectacle of Nature," translated from the French by Mr. Humphreys, the first edition of which was published about the beginning of the century, and the second edition, to which the writer has had access, about 1807.

The most important work, however, from a scientific point of view, and that which gives the most accurate statements pertaining to the relation of chemistry to agriculture, is a compilation of the lectures of Sir Humphry Davy. These lectures, delivered before the Royal Agricultural Society of England, were first published in England in 1813.

Another work of a more popular nature, and yet containing a résumé of the knowledge of that time concerning the relations of chemistry to agriculture, is entitled "The Rural Socrates; or, An account of a celebrated philosophical farmer, lately living in Switzerland, known by the name of Kliyogg." It was translated from the German by Benjamin Vaughan, a writer distinguished in many fields of work and a personal friend of Joseph Priestley. This work was published in Hallowell, Me., by Peter Edes in 1800.

Chemistry as a science has undergone such a wonderful transformation during the century as to make any just comparison of its relation to any particular industry at the present time with that it held a hundred years ago somewhat difficult. We regard with a feeling akin to compassion the ideas entertained one hundred years ago in reference to chemistry, especially in its relations to agriculture; but the pride we may feel in our present knowledge of this science should not be allowed to carry us too far, since at the end of the next century the writer who shall undertake a review of this subject may look with equal compassion on the views we now entertain.

The efforts which were made by Lavoisier and his school to place the science of chemistry upon a sure foundation some twenty-five years before the beginning of the century, although making great progress, had not yet entirely dominated the world of chemical theory. The crude notions of the earlier chemists concerning phlogiston, phlegms, essential oils, exudations, evaporation, and other processes still held sway, and agricultural chemistry was probably the last of the different branches of chemical science to be liberated from the thraldom of these erroneous theories. In spite of this fact, however, the observations which scientific men had made of the chemical aspects which agricultural science possessed are not without value nor are they wholly false.

KNOWLEDGE OF THE COMPOSITION AND FUNCTIONS OF SOILS.

By far the most accurate account of the composition of the soil, as it was understood at the beginning of the century, is furnished by Sir Humphry Davy. According to Davy the substances which constitute the soil "are certain compounds of the earths, silica, lime, alumina, magnesia, and of the oxides of iron and magnesium; animal and vegetable matters in a decomposing state, and saline, acid, or alkaline combinations." Minute descriptions are given of the various elements composing the soil, and for the most part these descriptions represent the state of our knowledge even at the present time. Silica is described as a compound of oxygen and silicum. Lime is

1Agricultural Chemistry, pp. 154 et seq.
stated to exist in soils usually united with carbonic acid, and sometimes with phosphoric and sulphuric acids. Lime itself is said to consist of 40 parts by weight of calcium and 15 of oxygen, which is very nearly the composition assigned to the substance CaO at the present time. Alumina, with less accuracy, is described as being composed of 33 parts by weight of aluminum and 15 of oxygen. Magnesia is described as existing in combination with carbonic acid. Two oxids of iron are mentioned, the brown and the black, and their chemical composition as understood at that time is given. The oxid of manganese, or manganesum, as Davy calls it, is stated to be distinguished from the other substances found in the soil by its property of reducing muriatic acid and converting it into chlorin. Vegetable and animal matters are to be known by their sensible qualities and by their property of being decomposed by heat. The saline compounds of soils are described as common salt, sulphate of magnesia, sometimes sulphates of iron, nitrates of lime and of magnesia, sulphate of potassa, and carbonates of potassa and soda. These compounds Sir Humphry regards as of so little importance that he says it is not necessary to describe their characteristics minutely.

The methods of soil analysis, many of which are still in use at the present time, are fully described. Upon the whole, most of them, however, are crude and unsatisfactory, and could not possibly have led to correct ideas of the composition of the soil. Davy further adds: "In the first trials that are made by persons unacquainted with chemistry, they must not expect much precision of result. Many difficulties will be met with; but in overcoming them the most useful kind of practical knowledge will be obtained, and nothing is so instructive in experimental science as the detection of mistakes. The correct analyst ought to be well grounded in general chemical information; but perhaps there is no better mode of gaining it than that of attempting original investigations."

Davy fully recognized that the soil is the source of nourishment for plants, as he says in another place: "Plants being composed of no locomotive powers, can grow only in places where they are supplied with food; and the soil is necessary to their existence, both as affording them nourishment and enabling them to fix themselves in such a manner as to obey those mechanical laws by which their radicles are kept below the surface and their leaves exposed to the free atmosphere. As the systems of roots, branches, and leaves are very different in different vegetables, so they flourish most in different soils. The plants which have bulbous roots require a looser and a lighter soil than such as have fibrous roots, and the plants possessing only short fibrous radicles demand a firmer soil than such as have taproots or extensive lateral roots."

Of vegetable and animal matters Davy says: "Vegetable or animal matters when finely divided not only give coherence, but likewise
softness and penetrability; but neither they nor any other part of the soil must be in too great proportion, and a soil is unproductive if it consist entirely of impalpable matters." He says of mineral constituents: "Pure alumina or pure silica, pure carbonate of lime, or carbonate of magnesia are incapable of supporting healthy vegetation. No soil is fertile that contains as much as 19 parts out of 20 of any of the constituents that have been mentioned."

Again, he says: "In all cases the ashes of plants contain some of the earths of the soil in which they grow; but these earths, as may be seen by the table of ashes afforded by different plants given in the last lecture, never equal more than one-fiftieth of the weight of the plant consumed. If they be considered as necessary to the vegetable, it is as giving hardness and firmness to its organization. Thus, it may be mentioned that wheat, oats, and many of the hollow grasses have an epidermis principally of the siliceous earths, the use of which seems to be to strengthen them and defend them from the attacks of insects and parasitical plants."

The physical quality of earths in their relation to water are fully exploited by Davy. He says: "The power of soils to absorb water from the air is much connected with fertility. When this power is great, the plant is supplied with water in dry seasons, and the effect of evaporation in the day is counteracted by the absorption of aqueous vapor from the atmosphere, by the interior parts of the soil during the day, and by both the exterior and the interior during the night."

In regard to the food of plants, Sir Humphry states: "Water and the decomposing animal and vegetable matter existing in the soil constitute the true nourishment of plants, and as the earthy parts of the soil are useful in retaining water, so as to supply it in the proper proportions to the roots of the vegetables, so they are likewise efficacious in producing the proper distribution of the animal or vegetable matter; when equally mixed with it, they prevent it from decomposing too rapidly, and by their means the soluble parts are supplied in proper proportion."

In speaking of the derivation of soils from rocks, he says: "The best natural soils are those of which the materials have been derived from different strata, which have been minutely divided by air and water and are intimately blended together; and in improving soils artificially the farmer can not do better than imitate the processes of nature. The materials for the purpose are seldom far distant; coarse sand is often found immediately on chalk, and beds of sand and gravel are common below clay. The labor of improving the texture or constitution of the soil is repaid by a great permanent advantage; less manure is required, and its fertility insured. The capital laid out in this way secures forever the productiveness and consequently the value of the land."
Commissioner Newton, in his first Annual Report, paid a fitting tribute to the services of Sir Humphry Davy in establishing agricultural chemistry as a separate department of science. He says, speaking of the board of agriculture established by Pitt in 1793:

More than all, the board was instrumental in employing Sir Humphry Davy to make those experiments which are not only an honor to intellect, but which established agricultural chemistry as a department of science, and are of inestimable value. He delivered his lectures on this subject in 1802. The fundamental principle which he developed and demonstrated was this—that the productions of the soil derive their component elements, which for the most part are hydrogen, oxygen, and nitrogen, either from the atmosphere by which they are surrounded or from the soil in which they grow. He showed that the process of vegetation depends upon the perpetual assimilation of various substances to the organs of the plants in consequence of the exertion of their living powers and their chemical affinities, stimulated chiefly by moisture, light, and heat. The discoveries in chemical science before Davy's time had undoubtedly prepared the way for his triumph, but he is none the less entitled to praise. He first recognized a plant as a living thing, the laws of whose existence were to be studied in order to develop a perfect growth. He showed, by analysis of soils and plants, what properties and conditions would best furnish the elements needed in cultivation.

KNOWLEDGE OF FERTILIZERS AND MANURES.

The chemical knowledge of the composition and functions of fertilizers at the beginning of the nineteenth century was extremely nebulous. Experience of a wholly empirical nature had shown from the earliest history of agriculture the value of certain refuse products of the stable and the barnyard in increasing the yield of crops; but the component parts of these materials and the manner in which they acted were entirely unknown. It was the custom in many of the older countries for the farmers to increase the litter of the farmyard by gathering leaves and twigs, which were used in bedding the animals. As, for instance, it was said of Kliyogg: "He is attentive also to gather all the dried leaves, moss, and rushes from his ground that can serve for litter. * * * A compost dunghill appears to him an object of so great importance to the improvement of land that of all branches of labor he regrets the want of assistance in this the most. * * * In prosecution of this design, in autumn, during the moon's increase, Kliyogg goes into his wood with a hedge bill to prune the supernumerary branches of fir and pine trees. * * * These he binds into faggots and carries home. * * * At leisure hours, and especially in long winter evenings, he prepares these faggots for the purposes intended. * * * By this method he amasses many proper materials for good manure."¹

Kliyogg was also careful to preserve the liquid manures which exuded from his stables, and for this purpose he constructed trenches in his cow houses. It is interesting to know that, unwittingly, he had

¹The Rural Socrates; or, An Account of a Celebrated Philosophical Farmer, Lately Living in Switzerland, Known by the Name of Kliyogg, p. 8.
discovered the true function of much of this material, which he regarded as a ferment. The record says: "Thus placed, it receives the urine and dung of his cattle, and being always kept half full of water, it forms a thick mixture and serves as a ferment, with which a very great quantity of water may in a very short time be converted into liquid manure. One portion of this ferment being mixed with seven portions of the freshest spring water soon makes the whole become corrupt, especially if the reservoir in which the mixture is made is of wood and placed in a warm situation, or if an artificial heat is substituted in case a natural heat is wanting. By means of this fermentation an excellent manure is produced, which proves the best assistant which can be given to such meadow and arable lands as are naturally dry."

The earlier accounts of scientific agriculture at the beginning of the century recognized the great value of gypsum as a fertilizing material. All the writers refer favorably to its use. The use of gypsum as a fertilizer is said to have been the discovery of the Rev. Mr. Meyer, pastor of Kupferzell, Germany. Mr. Meyer published a detailed account of the manner of using gypsum. According to the method described by him, gypsum should be spread in its natural state after being reduced to powder, and is useful upon meadows containing both the common and cultivated grasses. Mr. Meyer also found gypsum valuable with peas, vetches, lentils, oats, rye, and tobacco. Its most surprising effect, however, was upon clover, and this in soils the most dry and arid. On marshy ground it was found to produce no good effect. It is urged that gypsum should be spread upon the grass or grain before it begins to shoot. Upon meadows, the best time for spreading it is stated to be at the melting of the snow, and upon fields of grain, as soon as they are sown. Benjamin Vaughan, the translator of "The Rural Socrates," says that at the end of the last century and at the beginning of the present gypsum was used largely in the United States, and he refers to the writings of Judge Peters, Robert Morris, Dr. Mitchill, Mr. Bordley, and others on the subject.

The use of marl was also fully understood at the beginning of the century. Since the time of the Roman conquest, and probably before, the marl beds of northern France and southern Belgium have been constantly exploited. Great hollows are found in many of the fields of northern France made by the excavation of marl many centuries ago. Kliyogg calls the marl bed "that mine of farming gold," and says: "I owe to this marl not only abundant harvests, but the character of my children. It is true that they murmured against me at first for employing them in hard labor; even during the winter. ** But at length the rich harvests with which Providence blessed us

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1 The Rural Socrates; or, An Account of a Celebrated Philosophical Farmer, Lately Living in Switzerland, Known by the Name of Kliyogg, p. 128.
2 Ibid., pp. 128 and 129.
forced them to confess that I had said nothing which was not both true and useful."  

The true function of marl, however, was but little understood, and even its chemical composition was practically unknown by those using it.

In the article on husbandry, in "The Spectacle of Nature," the Prior, in conversation with the Chevalier, says in regard to manure: "This manure, which completes what the dews of heaven had begun, is the most contemptible substance upon the face of the earth, and is chiefly composed of the litter taken from stables and sheepfolds; dove houses, hencoops, and the dwellings of all domesticated animals furnish manures that differ in their degrees of heat, and which being blended together, as well as quenched and corrected by each other, replenish the land with all the fertility it had lost." Among other substances which the Prior mentioned as being used for manures are straw, stubble, shells of pulse, useless leaves, refuse of garden herbage, rotten wood, chimney and oven soot, rags, hair of animals, cuttings of leather, skins of beasts, bark of trees, lees of wine, sediments of oil, malt dust, tanners' bark, dyers' lees, soapsuds, of which last it is said, "which are commonly thrown out of the laundry as useless, though soap is impregnated with oils and salts, which are the principal elements of plants."

The Prior also says: "No kind of manure has more prolific qualities than the soil which is swept from populous cities, and especially those where a great number of kitchens and dyers of wool are continually discharging into the streets a fat and oily sediment, which is very beneficial to corn."

The value of ashes is fully recognized, in the essay on husbandry, by the Prior, who says that they can supply the place of all the rest if a sufficient quantity can be obtained. The ashes of wood are preferred to those of any other substance. He advises the burning of turf for the purpose of securing the ashes. The methods of forming composts with ashes are fully described.

The prevailing idea at that time that oil is one of the most valuable of manures is developed in his description, it being stated that "oil and salts constitute the chief merit of the manure."

The fact that the principal value of the ashes is due to the potash and phosphoric acid which they contain was not even suspected by the earlier scientific agriculturists. The early agriculturists in our country were imbued with the customs of their European homes in regard to the use and value of manure, although upon the virgin lands there seemed to be but little necessity for the application of fertilizing substances. The necessity of fertilizers, however, soon became evident, especially on lands planted continuously to cereals and to tobacco. When the first abundant crops, due to the virgin fertility of the soil, began to

1 The Rural Socrates, pp. 143 and 144.  2 The Spectacle of Nature, pp. 231 and 232.
diminish, the colonists received a valuable lesson in the use of artificial fertilizers from Squanto, one of the leading Indians of the New England coast. In Governor Bradford's "History of Plimouth Plantation" is given an account of the early agricultural experiences of the Plymouth colonists. In April, 1621, at the close of the first long, dreary winter, "they [as many as were able] began to plant their corne, in which service Squanto [an Indian] stood them in great stead, showing them both ye manner how to set it, and after how to dress and tend it. Also he tould them, axcepte they got fish and set with it [in these old grounds], it would come to nothing; and he showed them yt in ye middle of April, they should have store enough come up ye brooke by which they begane to build and taught them how to take it."

In George Mourt's "Relation; or, Journal of the beginning and proceedings of the English Plantation settled at Plimouth, in New England, by certain English adventurers, both merchants and others," London, 1622, it is said:

We set the last spring some twenty acres of indian corn, and sowed some six acres of barley and pease, and according to the manner of the Indians, we manured our ground with herrings, or rather shads, which we have in great abundance and take with great ease at our doors. Our corn did prove well, and, God be praised, we had a good increase of indian corn, and our barley indifferent good.

Thomas Morton, in his "New England Canaan," London, 1632, wrote of Virginia:

There is a fish (by some called shadds, by some allizes) that at the spring of the yeare passe up the rivers to spawn in the pond, and are taken in such multitudes in every river that hath a pond at the end that the inhabitants do unh their ground, with them. You may see in one township a hundred acres together set with these fish, every acre taking 1,000 of them, and an acre thus dressed will produce and yield so much corn as three acres without fish; and least any Virginea man would infer hereupon that the ground of New England was barren, because they use more fish in setting their corne, I desire them to be remembered, the cause is plain in Virginea, they have it nob to sett. But this practice is onely for the indian maize (which must be set by hands), not for English grain; and this is therefore a commodity there.

The following amusing quotation is from the records of the town of Ipswich, Mass., May 11, 1644:

It is ordered that all the doggs for the space of three weeks from the publishing hereof shall have one legg tyed up, and if such a dogg shall break loose and be found doing harm the owner of the dogg shall pay damage. If a man refuse to tye up his dogg's leg, and hee bee found scraping up fish in a corn field, the owner thereof shall pay twelve pence damage, beside whatever damage the dogg doth. But if any fish their house lotts and receive damage by doggs, the owners of these house lotts shall bear the damage themselves.

It is thus seen that even on the old ground cultivated by the Indian before the advent of the colonists it was not possible to raise good crops except by the artificial manuring which has been described above. Little was known, however, of the nature of these fertilizing:
materials and the manner in which they nourished plants. The first real knowledge of fertilizing materials which was in vogue in this country came from the republication of Sir Humphry Davy's "Agricultural Chemistry" and its distribution throughout the colonies. It may be stated that this book produced the first real impression, of a scientific nature, of the relation of chemistry to the progress of agriculture. Many of the lectures given by Sir Humphry Davy were on the subject of manures, in which he treated of the manures of vegetable and animal origin, of the manner in which they became the nourishment of the plant, of fermentation and putrefaction, of mixed manures, of general principles in respect of the use and application of manures of mineral or animal origin, of fossil manures, of lime, of gypsum, of alkaline salts employed as manures, of alkalies, and of common salt. He also gave a lecture on the improvement of land by burning and the chemical principles which underlie this operation. He first announced the general principles that all manures must practically be dissolved before they can enter the organism of the plant. He says: "The pores in the fibers of the roots of plants are so small that it is with difficulty they can be discovered by the microscope. It is not, therefore, probable that solid substances can pass into them from the soil."\(^1\)

Sir Humphry supposed that sugar was a valuable fertilizing material, because when he grew plants in a solution of sugar, jelly, and mucilage he found that they grew vigorously. He recognized the fact that vegetable and animal substances, before they can become useful as plant food, must be changed in some way, since he says, "They can only nourish the plant by affording solid matters capable of being dissolved by water or gaseous substances capable of being absorbed by the fluids in the leaves of vegetables. * * * The great object in the application of manure should be to make it afford as much soluble matter as possible to the roots of the plants, and that in a slow and gradual manner, so that it may be entirely consumed in forming the sap or organized parts of the plant. * * * Vegetable manures in general contain a great excess of fibrous and insoluble matter, which must undergo chemical changes before they can become the food of plants."\(^2\)

Chief among these changes he regarded fermentation, thus recognizing at that early date the great principle of change which organic matters must undergo before they become useful as plant foods. Sir Humphry, however, was familiar only with the variety of fermentation which produced carbonic acid and alcohol, and of course had no knowledge of the really essential fermentation, from a fertilizing point of view, which such substances undergo. He, however, realized that there was a fermentation of a different kind, because he says: "Animal matters in general are more liable to decompose than vegetable

\(^{1}\)Agricultural Chemistry, p. 269. 
\(^{2}\)Ibid., pp. 272 and 273.
substances; oxygen is absorbed and carbonic acid and ammonia formed in the process of their putrefaction. They produce fetid compound elastic fluids, and likewise azote.”

The principal substances which are found in animal manures, according to Davy, are gelatin, fibrin, mucus, animal fats and oils, and albumin and urea. The effect of sterilization or pasteurization in preventing the decay of animal matters is fully recognized by Davy in describing what he calls “Appert’s method of preserving animal and vegetable substances,” which is practically the pasteurization of the present day. He says: “This method is by filling a vessel of tin plate or glass with the meat or vegetables; soldering or cementing the top so as to render the vessel air-tight, and then keeping it half immersed in a vessel of boiling water for a sufficient time to render the meat or vegetables proper for food. In this last process it is probable that the small quantity of oxygen remaining in the vessel is absorbed; for on opening a tinned iron canister which had been filled with raw beef and exposed to hot water the day before, I found that the minute quantity of elastic fluid which could be procured from it was a mixture of carbonic-acid gas and azote.”

It appears, therefore, that the process of pasteurization is at least as old as the nineteenth century.

Sir Humphry makes the following additional observation: “Where meat or vegetable food is to be preserved on a large scale for the use of the navy or army, for instance, I am inclined to believe that by forcibly throwing a quantity of carbonic acid, hydrogen, or azote into the vessel by means of a compressing pump, similar to that used for making artificial seltzer water, any change in the substance would be more effectually prevented. No elastic fluid in this case would have room to form by the decomposition of the meat, and the tightness and strength of the vessel would be proved by the process. No putrefaction or fermentation can go on without the generation of elastic fluid, and pressure would probably act with as much efficacy as cold in the preservation of animal or vegetable food.”

The use of oil cakes for fertilizing is recommended by Davy, and rape cake and linseed oil are mentioned, although the knowledge that their value depends upon their nitrogenous bodies did not obtain. The fertilizing value of malt dust, which consists of the powdered radicle of malt, is attributed to the amount of sugar which it contains. Linseed cake is said by Davy to be too valuable as a food for cattle to be employed as a manure. Seaweed is also recommended as a valuable fertilizing material. He also dwells upon the value of wood ashes, animal carcasses, and fish for fertilizing purposes. The value of fish is explained by Davy as follows: “It is easy to explain the operation of fish as a manure. The skin is principally gelatine, which, from its slight state of cohesion, is readily soluble in water;

1Agricultural Chemistry, p. 274.  
2Ibid., pp. 278 and 279.
fat or oil is always found in fishes, either under the skin or in some of the viscera, and their fibrous matter contains all the essential elements of vegetable substances."

The curious idea that the oil is the chief manurial substance is further advanced in the statement that blubber is a valuable manure. Probably the real value of the blubber was from the minute quantity of nitrogen which it contained.

The value of bones is recognized by Davy. It is stated that "the more divided they are the more powerful are their effects." Bone dust and bone shavings, according to Davy, may be advantageously employed, and he recognizes that the basis of bone is the phosphate of lime, and also that it contains gelatin and cartilage, which seem to be of the same nature as coagulated albumin. It is evident that horn appeared to Davy to be a more powerful manure than bone. The refuse of the slaughterhouses, as skin, leather, hair, feathers, and blood, were regarded as valuable by him.

The value of guano as a fertilizer was also fully recognized at the beginning of the century, a much earlier date than is generally supposed. Davy says that "the value of guano as a fertilizer is easily inferred from its composition. It contains one-fourth part of its weight of uric acid, partly saturated with ammonia and partly with potassa, some phosphoric acid and lime, and small quantities of sulphate and muriate of potassa, and a little fatty matter." The value of lime for fertilizing purposes is fully discussed by Davy and the principles of its application most justly set forth. Magnesia was supposed to have almost equal value. The value of gypsum was also thoroughly appreciated. The use of ashes of burned peat was said to be very beneficial.

The value of phosphorus as a plant food was not appreciated, even at the time of Davy, and no large deposits of mineral phosphates were known. In speaking of phosphate of lime, he says: "It exists in some places in these islands native, but only in very small quantities. * * * It is probably necessary to corn crops and other white crops. * * * Bone ashes ground to powder will probably be found useful on arable lands containing much vegetable matter, and may perhaps enable soft peats to produce wheat; but the powdered bone in an uncalcined state is much to be preferred in all cases when it can be procured."

Davy thus unwittingly shows the great loss of fertilizing matter which attends the burning of bones by the destruction of the nitrogenous bodies which they contain, but was not aware that this loss diminished their utility. Speaking of wood ashes, he says: "Wood ashes consist principally of the vegetable alkali united to carbonic

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1 Agricultural Chemistry, p. 289.  
2 Ibid., pp. 315 et seq.  
3 Ibid., p. 297.  
acid, and as this alkali is found in almost all plants, it is not difficult to conceive that it may form an essential part of their organs."¹

The vegetable alkali referred to is potash, and its efficiency was supposed to be due to the fact that it rendered soluble carbonaceous and other substances and permitted them to be absorbed by the tubes in the radicle fibers of plants.

In regard to soda, which he calls "mineral alkali,"² in distinction from vegetable alkali, he regards it of equal value. The use of common salt is also urged, because it is offensive to insects.

The observations made by Davy on the use of nitrate of potash are extremely interesting. He says: "Sir Kenelm Digby states that he made barley grow very luxuriantly by watering it with a very weak solution of niter; but he is too speculative a writer to awaken confidence in his results. This substance consists of 1 portion of azote, 6 of oxygen, and 1 of potassium, and it is not unlikely that it may furnish azote to form albumen or gluten in those plants that contain them; but the nitrous salts are too valuable for other purposes to be used as manures."³ This is a very apropos observation, since it was made at the time of the Napoleonic wars.

Sulphate of potassium, Davy says, is considered a valuable manure by Dr. Home. Mr. Naismith questions his results, and quotes experiments hostile to his opinion, and, as he conceives, unfavorable to the efficacy of any saline manure.³

In a general view of the whole subject of the use of saline substances, Davy says:

It is unnecessary to discuss to any greater extent the effects of saline substances on vegetation, except the ammoniacal compounds, or the compounds containing nitric, acetic, and carbonic acid; none of them can afford by their decomposition any of the common principles of vegetation—carbon, hydrogen, and oxygen.

The alkaline sulphates and the earthy muriates are so seldom found in plants, or are found in such minute quantities, that it can never be an object to apply them to the soil. It was stated in the beginning of this lecture that the earthy and alkaline substances seem never to be formed in vegetation, and there is every reason, likewise, to believe that they are never decomposed, for after being absorbed they are found in their ashes.⁴

It is thus seen that as late as 1815 there was no practical appreciation of the use of mineral fertilizers, even in the most advanced studies of the relation of chemistry to agriculture, and the notions regarding the application of vegetable and animal matters for fertilizing purposes were in most cases erroneous and the knowledge of their good effects principally empirical.

KNOWLEDGE OF THE COMPOSITION OF AGRICULTURAL CROPS.

All that was practically known at the beginning of the century in regard to the chemical composition of agricultural products is contained in the third lecture given by Sir Humphry Davy before the

British Board of Agriculture. It will not be necessary, therefore, to give the opinions of other authors on this subject.

Vegetables are thus defined: "Vegetables are living structures distinguished from animals by exhibiting no signs of perception or of voluntary motion; and their organs are either organs of nourishment or of reproduction; organs for the preservation and increase of the individual, or for the multiplication of species."

Nineteen different bodies or classes of bodies were recognized by Davy as constituting vegetable substances in general. These are: "1, gum, or mucilage, and its different modifications; 2, starch; 3, sugar; 4, albumen; 5, gluten; 6, gum elastic; 7, extract; 8, tannin; 9, indigo; 10, narcotic principle; 11, bitter principle; 12, wax; 13, resins; 14, camphor; 15, fixed oils; 16, volatile oils; 17, woody fiber; 18, acids; 19, alkalies, earths, metallic oxides, and saline compounds."

Gum, or mucilage, which is a certain variety of gum, is described as being easily soluble in water and insoluble in alcohol. All the varieties of gum and mucilage were regarded as valuable plant foods, as well as useful in some of the arts, as, for instance, in calico printing.

Starch is described as being soluble in boiling water.

Sugar is regarded as furnished chiefly by the sugar cane, and only small quantities by other sources. It is remarkable that Davy describes a method, which he proposed for purifying raw sugar, which has lately been made the subject of patents in this and other countries, namely, by washing the crystals, or raw sugar, with a sugar sirup. The sugar which is derived from the beet is said to be peculiar in its nature and to agree with the sugar of grapes in its general properties and in having a bitter taste. The properties of sugar, as an animal food, were recognized by Davy, who states that the British market was overstocked with this article from the West India Islands, and for this reason proposals had been made for using it as a food for cattle. His opinion that it was a valuable food for vegetables has already been cited.

Vegetable albumin was known to exist in the juice of the papaw tree, and tables of analyses are given showing its percentage composition.

The properties of gluten are described, and it is said to be distinguished from albumin chiefly by its insolubility in water. Its high nutritive value was also appreciated, and it is stated to be one of the most nutritive of vegetable substances.

Under the head of "extract" is described a variety of substances obtained from different plants, evidently mixtures of various bodies. Extract, it is said, in its pure form can not be used as an article of food, but it is probably nutritive when united to starch, mucilage, or sugar.

Tannin is declared to be of no nutritive value.

1 Pages 55 et seq.
The other bodies found in plants, as enumerated by Davy, are of no value, from a food point of view, except the oils, which he divided into two varieties, namely, fixed and volatile.

Among the acids which were known to exist at that time in the vegetable kingdom, are mentioned oxalic, citric, tartaric, benzoic, acetic, carbonic, and prussic.

Of the fixed alkalies, potash is recognized as being the one common to the vegetable kingdom.

Of the mineral acids, Davy states that phosphoric, sulphuric, muriatic, and nitric exist in many saline compounds in the vegetable kingdom, but they can not be properly considered as vegetable products.

Davy held to the opinion, which was prevalent in his time, and which still exists in many quarters, that the rigidity of plants is due solely to the quantity of silica which they contain. His views of the composition of plants were the most advanced and scientific which had ever at that time been proposed, and their scientific value especially may be recognized by a comparison with the theory of plant composition exposed by Dr. Thomson in his elaborate and learned system of chemistry. He quotes Thomson as describing six vegetable substances, which he calls mucus, jelly, sarcoecol, asparagin, inulin, and ulmin. Davy does not agree with this view, and says: "It is probable, from the taste of sarcoecol, that it is gum combined with a little sugar. Inulin is so analogous to starch that it is probably a variety of that principle; ulmin has been lately shown by Mr. Smithson to be a compound of a peculiar extractive matter and potassa; and asparagin is probably a similar combination."¹

It is not to be wondered at that the views, even of the most advanced kind, concerning the composition of plants were of such an erroneous nature when we consider the state of analytical chemistry at that time. Sir Humphry Davy was, without doubt, the most skillful and accurate chemist of his time or of any time that preceded him, and the wonder is that he could have reached such correct results with the methods of analysis which he himself describes.

In regard to the theoretical composition of bodies resembling each other in vegetable substances, Davy says:

Gum and sugar afford nearly the same elements by analysis, and starch differs from them only in containing a little more carbon. The peculiar properties of gum and sugar must depend chiefly upon the different arrangement or degree of condensation of their elements; and it would be natural to conceive from the composition of these bodies, as well as that of starch, that all three would be easily convertible one into the other, which is actually the case.

At the time of the ripening of corn the saccharine matter in the grain and that carried from the sap vessels into the grain, becomes coagulated and forms starch; and in the process of malting, the converse change occurs. The starch of grain

¹Third lecture by Sir Humphry Davy before the British Board of Agriculture, p. 118.
is converted into sugar. As there is a little absorption of oxygen and a formation of carbonic acid in this case, it is probable that the starch loses a little carbon, which combines with the oxygen to form carbonic acid; and probably the oxygen tends to acidify the gluten of the grain, and thus breaks down the texture of the starch, gives a new arrangement to its elements, and renders it soluble in water.¹

The first table showing the comparative nutritive value of different foods ever published was probably that constructed by Davy, in which all the more common vegetable varieties of foods are compared in respect of their proportions of nutritive matter. These nutritive bodies are grouped under four heads—mucilage, or starch; saccharin matter, or sugar; gluten, or albumin; and extract. Rather strangely, the oils and fats of vegetables are not regarded as of sufficient nutritive importance to find a place in the table.

The value of gluten in bread making is fully recognized in Davy's studies of the composition of plants, and some of the earliest observations upon the nutritive value of different kinds of wheat are found in his writings. He says:

It is probable that the excellence of the different articles as food will be found to be in a great measure proportional to the quantities of soluble or nutritive matters they afford; but still these quantities can not be regarded as absolutely denoting their value. Albuminous or glutinous matters have the characters of animal substances; sugar is more nourishing, and extractive matter less nourishing, than any other principles composed of carbon, hydrogen, and oxygen. Certain combinations likewise of these substances may be more nutritive than others.²

It was also recognized that flour made from hard wheat is to be more esteemed than that made from soft, even when there is no difference in the process of making them into bread; but the flour from hard wheat will absorb and retain more water in making into bread, and will consequently produce a greater weight of bread. It is shown by chemical analysis that this difference in incorporating hard and soft wheat in bread making is due to the larger amount of gluten contained in the hard wheat.

REVIEW OF THE EARLY KNOWLEDGE OF THE RELATION OF CHEMISTRY TO AGRICULTURE.

It is now possible to give a general view of the knowledge of the relations which chemistry held to practical agriculture at the beginning of the century. In regard to soils, some general notions of a true character were held as to their composition. The real plant foods in the soil, however, were not appreciated. While in a general way it was recognized that phosphoric acid, potash, and lime entered into the composition of the plant, it is evident from a study of the literature of the time that silica was regarded as more beneficial to the plant than any of the other mineral matters mentioned. The manner in which the food was furnished to the plant was imperfectly

¹ Third lecture by Sir Humphry Davy before the British Board of Agriculture, pp. 127 and 128.
² Ibid., p. 151.
known, save that it was generally conceded that the mineral mat-
ters must first enter into solution before they could be distributed
throughout the plant.

In regard to the physical nature of the soil, it was a matter of com-
mon observation that it had much to do with the efficacy of plant
growth. The open and porous soils were more prized than those of
a hard and impenetrable nature, and the general distinctions between
sandy, loamy, and clayey soils were well understood.

The notion was extremely prevalent that the soils serve more as a
resting place and support for the root system of the plants, while the
materials for plant growth in some way resemble exudations, or
emanations, which come partly from the soil itself and partly from the
atmosphere. The actual chemical composition of soil was but little
understood, and this arose from the fact that the means of chemical
analysis were so meager and its processes so unsatisfactory as to pre-
clude the possibility of securing exact data. Nevertheless, a reason-
ably accurate knowledge was had of the chief constituents of the soil,
if not of the functions which they played in plant growth. That the
soil was a vehicle for the administration of the nourishing elements
of food, was not fully appreciated at the beginning of the century.
The nitrogen, or azote, as it was called in that day, was supposed to
reach the plant exclusively in the form of ammonia, and no accurate
knowledge of the relation of the soil to the production of azotized
foods was extant.

Perhaps, however, the most striking error in connection with the
notions relating to the constitution of the soil itself in respect of plant
growth is found in the fact that the true functions of phosphoric
acid and potash in the nutrition of plants were imperfectly, if at all,
understood by even the most advanced agricultural chemists of that
day.

It is true that the chemical composition of manures which were then
in use was not well known, nor were the processes by which manures
became available as plant food at all understood, but the practical
knowledge of the use of stable manures, of marls, of gypsum, and of
lime was generally diffused and acted upon. Of artificial manures,
other than those mentioned, little was known save that the aborigines
of the New England States had taught the early settlers the great
value of using fish as a fertilizer.

Some idea also was entertained of the value of the refuse of the
slaughterhouses for fertilizing purposes, and it was known that blood,
bone, and horn were useful in promoting the growth of crops, but
how and why were not understood.

The value of clover and other leguminous crops in increasing soil
fertility was recognized, but the causes which established this value
were not at all known. The process of fermentation was recognized
in the manufacture and preparation of manures, but the nature of
this fermentation was wholly unknown to the investigators and chemical agriculturists of that time. Empiricism in the use of manures through thousands of years had led to most valuable practical results, but little was due at that time to the discoveries and researches of chemistry. When we look at the knowledge which was possessed of the composition of plants, we do not wonder that the relations of the soil and of fertilizers to plant growth were so little understood. The methods of investigation in vogue were totally inadequate to reveal the true constitution of plants, and it is a matter of wonder to us at the present time that with such crude apparatus and such imperfect methods so much accurate knowledge could have been obtained. The processes of organic analysis had only just been introduced, and only the general constitution of the carbohydrates, as represented by the gums, mucilages, starches, and sugars of that day, was definitely established, but the percentage of nitrogen contained in the albumin and gluten recognized as existing in plants is scarcely more accurately known at the present day than it was then.

The more important organic acids also existing in plants had been discovered, separated, and identified, and in general it must be confessed that, in so far as the progress of chemistry relating to the composition of plants is concerned, the agricultural chemists of the beginning of the century are to be congratulated on the attainments which they had made. The weak point of their researches and investigations was that they had made no systematic effort to correlate the composition of plants and of the soil to the principles of plant growth. With their imperfect ideas of the nature of plant nutrition, it did not occur to them that a great system of scientific agriculture could be based upon investigations of this kind. They, however, had done enough to pave the way for the great impetus which the investigations of Liebig, Gilbert, Boussingault, and others gave to systematic agricultural chemistry some thirty or forty years later.

Scientific Agriculture About the Middle of the Century.

The Era of Liebig.

The publication of Liebig's work entitled "Chemistry in its applications to agriculture and physiology," in 1840, marked a complete change in the theories of chemistry in respect of agriculture existing at the beginning of the century as portrayed in preceding pages, and inaugurated the new science of agriculture, resting upon his investigations as a foundation. If Wurtz could say, "Chemistry is a French science, founded by Lavoisier, of immortal memory," with all the greater propriety may we say of the agriculture of to-day, "Agriculture is a chemical science, founded by Liebig, of immortal memory." "Perfect agriculture," Liebig says in the preface to the first edition of his book, "is the true foundation of all trade and industry; but a rational system of agriculture can not be formed without the
application of scientific principles, for such a system must be based on an exact acquaintance with the means of nutrition of vegetables and with the influence of soils and actions of manure upon them; this knowledge we must seek from chemistry, which teaches the mode of investigating the composition and of studying the character of the different substances from which plants derive their nourishment."

Within a year after Liebig's book was published it was translated into English, and soon thereafter was found in the languages of all the leading nations of the world. Liebig, however, must not be given the sole praise for the establishment of the true theory of scientific agriculture. Very much earlier in the century De Saussure, a celebrated French chemist and botanist, published his "Chemical researches on vegetation," and a decade before Liebig published his first work Boussingault, the most celebrated French agricultural chemist of the early part of the century, had produced a great many works on the relations of chemistry to agriculture. To both of these authors Liebig is largely indebted, and to each of them he gives full credit. The part which Davy took in preparing the way for these later investigations has already been pointed out.

Previous to the time of Liebig, as already indicated, it was commonly understood that organic substances, such as sugars and oils, were the chief foods of plants, either in the fresh state or in the partially decayed condition known as humus. In fact, the attitude of chemistry toward agriculture in the first four decades of the century was so strongly marked on this point that the whole system of plant nutrition, as understood at that time, might with propriety be designated the humus theory. Although other writers before the time of Liebig had intimated that the air and water, and not the earth, were the source of the carbon, oxygen, and hydrogen in plants, it must be admitted that it was through the researches of Liebig that the great principles of plant nutrition, founded on the elaboration of the elements of carbohydrates from the air and water, were fully developed. As in most other instances, however, the tendency of mankind to reach extremes was shown on this point. Liebig in his fight against the humus theory naturally went to the other extreme of denying that the humus took any part at all in plant nutrition. He based his chief objection to the humus theory on the ground that humus was practically insoluble, and that therefore it could not enter into the circulation of the plants. This argument we know now is not a valid one, but it served as the basis of an attack upon an erroneous theory which had established itself firmly in the minds of advanced agriculturists.

As early as 1807 Thompson observed that if plants be deprived of carbonic acid, they wither and die, and these observations had been confirmed by a great many observers. It was Ingenhousz who first made the observation that plants absorb carbonic acid only under the influence of sunlight, while in darkness the tendency of plants is to
give off rather than absorb this gas. It was urged against Liebig's theory of plants deriving their carbon from carbonic acid that the quantity of this gas in the air was so minute as to render Liebig's idea absurd. It is well known at the present time that the amount of carbonic acid in the air does not much exceed 4 parts in 10,000, and yet this quantity is amply sufficient to furnish the immense quantities of carbon of which the structures of plants are largely composed. It is easy to believe that in past ages, especially the one known by geologists as the Carboniferous Era, the quantities of carbonic acid in the air were much larger than at the present time and the amount of precipitation much greater. These two conditions, combined with the fact that the temperature of the earth must have been higher, account for the luxuriant growth of vegetable matters in those epochs, the gradual decay of which, under pressure, has provided the coal deposits of the present day. Liebig and his colaborers finally determined experimentally that organic matters were not suitable foods for plants, and that when sugar, gum, or starch are offered to a plant these compounds do not nourish it in any true sense. The vital functions of plant life consist rather in the elaboration of these organic bodies and other compounds from the inorganic elements on which the plants are fed. This is true, especially of green plants; whereas in the case of colorless plants the reverse is probably true, and these feed rather upon organic matter than upon inorganic. It was in this instance that Liebig's theory led him too far in denying the part of organic matter in any kind of plant life. Indeed, it has been found by researches carried on in the Division of Chemistry that the elements of humus may enter into the plant, as shown by the dark color of the juices of sugar cane grown upon humus soils and in the increase of amid nitrogenous matter in oats grown upon soils extremely rich in humus.

Long after the establishment of the practical truth of the doctrines of Liebig it was discovered that Lavoisier, fully sixty years before the time of Liebig's discoveries, had observed the same phenomena, although the information was not given to the public until the final publication of the papers of the great French chemist in 1862. It was then discovered that in one of Lavoisier's notes he had made this pregnant observation: "Plants derive the materials necessary for their formation from the air which surrounds them, from the water, and in general from the mineral kingdom." Thus, after all, we must attribute to Lavoisier the credit of having discovered the true theory of plant nutrition. The following from Lavoisier's observations wonderfully increases our admiration for the genius of this great man:

Animals feed on plants and on other animals fed by plants, so that the substances composing them are, in the last instance, always drawn from air and from the mineral kingdom. On the other hand, fermentation, putrefaction, and combustion continually restore to the air and to the mineral kingdom the principles borrowed from them by plants and animals.
While the theory of Liebig touching the formation of carbohydrates is fully corroborated by all modern investigations, in so far as the food of green plants is concerned, he never obtained the true solution of the method in which nitrogen was fed to plants. He assumed that the nitrogen was fed in the form of ammonia produced by the putrefaction of plants and animals, and, as is now well known, formed in the atmosphere by electrical discharges and in other ways. Liebig, as appears from his researches, was not at first aware of the importance of the part played by artificial fertilizers and manures in furnishing nitrogen to plants.

MINERAL THEORY OF PLANT NUTRITION.

The advances which chemistry has made in establishing the methods by which nitrogen becomes food for plants will be shown later. While the older view of the nutrition of plants is properly characterized by the term "humus," or "organic," theory, the school established by Liebig held to the theory of plant nutrition which may properly be denominated the "mineral" theory. Liebig was the first to study systematically the subject of mineral or artificial manures, and his views in this matter soon found their way into the United States. In the agricultural part of the Patent Office Report for the year 1845 Liebig contributes an interesting letter on the subject of artificial manures. In this letter it is believed the true principles connected with artificial manuring were first brought to the attention of American farmers. Among the artificial manures mentioned by Liebig in this letter are the earthy phosphates, of which at that time practically only one variety, namely, apatite, was known to exist. Liebig, however, in discussing the value of phosphate of lime as a fertilizer makes the curious mistake of saying that bones are most efficient for fertilizing purposes after they have been burned. It is strange that so keen an observer as Liebig could have been led into such a great error. He was right, however, in assuming that so far as the phosphate of lime is concerned, its utility as a plant food is determined largely by the rapidity with which it will enter into solution. It was for this reason that he assumed that the burned bones were more efficient than the unburned, arguing with great skill that the gelatin, or glue, which the bones contained had a tendency to keep the phosphatic material insoluble. He was the first who recommended the use of sulphuric acid on bones and mineral phosphates for the purpose of converting the lime into gypsum and securing the phosphoric acid in a state more easily soluble and assimilable. He also recommended the alkaline phosphates, such as those of soda and potash, as being excellent fertilizing substances on account of their high solubility. He recognized that the alkalies, namely, potash and soda, should be constituents of every rationally composed manure, since by them the original fertile condition of the fields is preserved. He observed that the soil
which contains alkalies in too small a quantity may be fertile for grain, but not necessarily so for turnips or potatoes, which require a great quantity of alkali. Sulphate of potash, common salt, and chlorid of potash were regarded as valuable manures, and the latter was said to be found in milk in large proportions.

Gypsum is recommended as a nourishment for leguminous plants. In speaking of the salts of ammonia, Liebig says it is certain that the azote, or nitrogen, of the plants is derived from the ammonia of the atmosphere or from a manure which is provided in the shape of animal fluid and solid excrement, and, further, that nitrogenous bodies are only useful in plant nutrition in proportion as they give up their nitrogen in the form of ammonia. In regard to decaying vegetable matters, he regarded them as useful only in so far as by their decay they afforded carbonic acid, but says that they are not indispensable in manure. As before mentioned, Liebig rather inclined to the extreme view in this case, denying to humus matters any proper place in plant nutrition. He fortifies the observations made by citing analyses of the ashes of some common crops, such as beans, peas, potatoes, clover, and hay. He also deduces the conclusion from these analyses that for stalks and leaves, manurial elements are required other than for seeds. The stalks and leaves contain no alkaline phosphates, but they require a rich supply of alkaline carbonates and sulphates. On the other hand, the carbonates are entirely wanting in the seeds, but the latter are very rich in phosphates. It is rather curious that Liebig should have fallen into the error of supposing that the carbonates in the ash existed in this state in the plants themselves; that he did not know that the occurrence of carbonates in the ash of the leaves and their nonoccurrence in the ash of the seeds are due solely to the presence of peculiar constituents of each, which permit a formation of carbonates on combustion in the ash of the leaves and prevent its formation in the ash of seeds on account of the excess of phosphoric acid, which at a high temperature completely expels carbonic acid from combination. In his letter to American farmers he calls particular attention to the fact that a manure which furnishes only one constituent element of plant food may rapidly exhaust the soil of all the other elements of fertility, and hence the necessity of supplying complete fertilizers instead of partial ones where the fertility of the soil is to be preserved or increased. He ascribes the fact that guanos have not always met the expectation of those who have used them to the presence in them of ammonia and alkaline phosphates and the practical absence of alkalies. He therefore urged particularly that fertilizers containing large quantities of potash and soda be used in conjunction with guanos in order to secure the best effects. In this letter Liebig also calls attention to the loss of the soluble elements of manure by lixiviation in the soil, and for this reason recommends that the manure of the barnyards be preserved, either in pits from which the
water can not escape or in covered sheds, to prevent the exhaustion of their soluble fertilizing ingredients. He says:

The reason why in certain years the influence of the best and most plentiful manuring is scarcely perceptible is that during the moist and rainy springs and summers the phosphates and other salts with alkaline bases, as also the soluble ammoniacal salts, are entirely or partly removed. Art must find out the means of reducing the solubility of the manuring substances to a certain limit; in a word, of bringing them into the same state in which they exist in a most fertile virgin soil, and in which they can best be assimilated by plants.

Looking forward, too, with a prophetic eye, Liebig saw a great industry which would grow out of his researches in the establishment of factories where artificial manures would be prepared for agricultural uses. He says at the close of his letter:

Manufactories of manure will be established in which the farmer can obtain the most efficacious manure for all varieties of soils and plants. Then no artificial manure will be sold whose exact amount of efficacious elements is not known, and this amount will be the scale for determining its value. Instead of the uncertainty of mere empiricism, all the operations of agriculture will be carried on with certainty, and instead of awaiting the results of our labors with anxiety and doubt, our minds will be filled with patience and confidence.

In reading over this admirable letter, contributed by request of the Commissioner of Patents to the American farmers by Professor Liebig, we are struck with the fact that fifty-five years ago the farmers of this country were provided with a creed for judging fertilizing materials which has undergone but little change as the result of all the researches which have been made since that time. It is hardly to be expected that even Liebig at that day would have correctly appreciated all the problems connected with fertilizing processes. The great principles, however, which underlie the application of artificial fertilizers were fully set forth, and the publication of this information to American farmers is therefore justly considered an epoch in the relations of chemistry to agriculture in the United States.

Although the views of Liebig were first promulgated in 1840, and, as indicated, were placed before the farmers of America as early as 1845, we find that as late as 1848 grave doubts of their accuracy were still entertained by those in charge of the Agricultural Division of the Patent Office. In the report for 1848 there is a long article, beginning on page 195, in which the views of Liebig are vigorously combated by references to authorities of his own country, chiefly von Thaer and Schulze. Sir Humphry Davy is held up in this discussion as an authority of greater value than Liebig. Considerable space is given to showing that it is quite improbable that the air, however rapidly it may move, can furnish enough carbon for the use of the plants; and Professor Schleiden, in his criticism of Liebig's theory, says: "Must we here adopt the ignorance of physics, or a wholly thoughtless insertion of it, as a cause of this monster of the wind theory?" It is concluded from a very elaborate study of the various theories relating to
the nutrition of plants that Liebig’s theory is liable to some fundamental objections, and the question is raised whether the humus theory, of which von Thaer was the chief apostle, supported, however, by the eminent authority of Professor Schulze, could be maintained against the objections which Liebig had urged to it. The Commissioner of Patents adds:

It may be thought by some we have devoted too much time and space to this subject, but Liebig’s works have been so extensively diffused in this country and in their charm of style and the enthusiasm with which the author entered into his discussions, the boldness displayed in his enunciation of his novelties, and other concurrent causes, they have exerted so great an influence in various sections that these facts seemed to justify the attempt to present, in as condensed a form as we could with any justice to the author, one of the ablest criticisms to which his principles have been subjected. Having in former reports presented the history of Liebig’s views, we may claim the right of giving, too, the other side of the question, and the more so since a right discrimination of the points is contained in the foregoing synopsis of Professor Schulze’s elaborate criticism.

It is evident, therefore, that even at this time, almost the middle of the century, the view was still stoutly maintained by eminent men that the organic matters of which plants are composed were derived chiefly from the soil, and not from the atmosphere and water. Hence it was, that with wonderful pertinacity the agricultural chemists clung to the theory that the organic matters of plants were directly derived from the decaying organic matters of the soil, and that therefore humus was the chief element in the nourishment of plants. (Pis. IV and V show portraits of some of the early and of the more recent workers in agricultural chemistry mentioned in this paper.)

RELATIONS OF CHEMISTRY TO AGRICULTURE AT THE PRESENT TIME.

METHODS BY WHICH RESULTS OF CHEMICAL STUDIES HAVE BEEN MADE OF PRACTICAL USE.

Among the methods which have been chiefly instrumental in bringing the results of chemical research into practical use in agriculture at the present time may be mentioned the following:

1. The teaching of agriculture in schools, colleges, and universities, and instruction given in farmers’ meetings.

2. The activity of agricultural colleges and experiment stations.

3. Instruction in the relations of chemistry to agriculture given in the agricultural press.

TEACHING OF AGRICULTURE IN SCHOOLS, COLLEGES, UNIVERSITIES, ETC.

It is rather difficult in discussing the first of these subjects to determine when the first instruction was given in schools, colleges, or universities in regard to the relations of chemistry to agricultural science. The first professorship evidently established for this purpose was founded at the University of Halle in 1727, when Frederick William, King of Prussia, established a professorship of rural economy,
Some Early Workers in Agricultural Chemistry.
in which the relations of chemistry to agriculture, as then understood, were developed and taught. The order in which similar chairs were established in other universities is hard to say, but in 1800 it is certain that other universities in Europe had followed the example of that of Halle.\footnote{Rural Socrates, p. 15.}

The importance of agricultural education was early recognized in the United States, as is seen in the Agricultural Reports of the Patent Office. In the report for the year 1847 a special plea is made for the establishment of agricultural education in the United States, as follows:

We might remark on the application of chemistry, animal and vegetable physiology, geology, and other sciences, with domestic economy, in reference to this great question of progress and as elements not without their bearing on the development of our agricultural resources. But these topics may be better touched upon in another part of this report, where we may treat of modes of cultivation and feeding of animals, with kindred topics.

There is one particular, however, which seems to claim our notice. This is agricultural education; a new era seems, in this respect, to be opening upon us. It may take years before we shall have our Hohenheims, Schliesheims, Tharands, and Moeglins, as in Germany and Prussia, but a beginning is made by attempts to establish such schools and colleges. There have been a number of the former set in operation by private enterprise, and in several of our colleges professors have been appointed who are well qualified to lecture on these subjects. In the time-honored universities of Harvard and Yale, two gentlemen who have enjoyed ample opportunities of pursuing their studies in Europe fill the chairs of the professorships. A man of experience also in science has recently been placed in this department in one of the colleges of Ohio. Much may be expected from the influence of these and similar positions in relation to this important subject; and here, too, we may refer our readers to the account given of agricultural education as well as of the agricultural convention at Breslau, by C. L. Fleischmann, esq. This account, with other articles of deep interest to the agriculturist of the United States, may be found in Appendix No. 1.

It is thus seen that more than half a century ago several agricultural schools, pure and simple, were established in Europe, and that at least two of the leading universities of this country, namely, Harvard and Yale, had established chairs of agricultural chemistry.

In the same report it is urged that traveling lecturers could diffuse agricultural knowledge, and the custom of the farmers' clubs and agricultural colleges of Great Britain in bringing together distinguished scientific men to give their views upon some topic selected as the subject of discussion is mentioned with favor. It is stated that the lectures of this kind indicate the principles of the application of manures, and deal with many other questions in which a knowledge of chemistry plays an important part.

In the article of Mr. Fleischmann, in the same report, on the agricultural schools of Germany, an account is given of his visit to one of the earliest and most famous of these schools, namely, that founded.
and conducted by von Thaer. In this school Dr. Trommer, a celebrated chemist of his time, was employed as a lecturer on chemistry and physical philosophy with reference to their employment in agricultural industry. On page 319 of the report it is stated that the lectures of Dr. Trommer were especially devoted to agricultural chemistry, illustrated by experiments required for a clear insight of the same, with constant regard to the use of these sciences in agriculture and the business therewith connected, such as breweries and distilleries, sirup and sugar making from beets and potatoes, and other matters of a technical nature relating to agriculture. Besides this, the student was given an opportunity of performing simple chemical analyses under a superintendent. There was also taught the outline of the physiology of plants, thus enabling the educated agriculturist, to penetrate deeper into the science and to secure a clearer insight into vegetation.

Thus early it is seen that agricultural chemical technics, and the principles upon which they are based, were made a principal part of the instruction given in agricultural schools to the young man engaged in acquiring a knowledge of agricultural science.

Space will not allow the tracing of the evolution of agricultural education step by step, and so we must pass over the early history and proceed to the consideration of the practical foundation of such education in the United States.

The first endowment for teaching agriculture in the United States was provided for Harvard University in 1837 by the will of Benjamin Bussey, and for Yale in 1846, and the first instruction in agricultural science from a chemical point of view was given at Yale in 1847. Since that time chairs of agricultural chemistry have been regularly established and maintained in these institutions.

RÔLE OF CHEMISTRY IN THE AGRICULTURAL COLLEGES AND EXPERIMENT STATIONS.

In a study of the impress which chemical research has made upon agriculture, there has been no factor during the past twenty years which can compare with the work of the agricultural experiment stations of the United States. Richly endowed as they are by the General Government, they have had every opportunity to secure the best results for practical agriculture.

In this work chemical science has played a very important part in the furthering of agricultural prosperity. Of the forty-nine directors of the stations at the present time, twenty were professional chemists at the time of their appointment. The selection of so many professional chemists was no mere chance, but evidently had some relation to the dominant position which the science of chemistry held to the promotion of agricultural chemical research. The list of directors of the agricultural experiment stations of Germany shows the same condition of affairs.
The great influence of chemistry on the agricultural experiment stations of this country is not measured alone by the number of professional chemists which is found in the directorates, but also in a comparison of this number to that of other scientific men holding similar positions. Very few of the other sciences are represented among the directors of stations, and no one of them can compare in its number of representatives to the science of chemistry. Among the working forces of the stations chemists also predominate. There are twice as many chemists employed in the stations as there are men engaged in any other professional scientific work. Statistics show that the number of chemists employed in the agricultural experiment stations of the United States is one hundred and fifty-seven, while the number of botanists is fifty and the number of entomologists forty-two. The number of employees belonging to other branches of science is very much less than that of the botanists and entomologists, and the total number of scientific men employed in all other branches of scientific work in the stations does not greatly exceed, even if it be equal to, the number of those employed in chemical research alone.

While dwelling upon the predominance of professional chemists in the directorate and upon the staff of the experiment stations it seems eminently proper to mention here in a special manner some of the earlier eminent chemists who have contributed so much to the value of chemical research in our agricultural colleges and experiment stations. Among these must be mentioned Prof. F. H. Storer, of Bussey Institute (Massachusetts), who first began the regular publication of a bulletin recording the work of the school and station, which has “set the step to which the bulletins from many other stations are still marching.” The bulletins of the Bussey Institute describing original research work on agricultural subjects have proved of the highest benefit to agriculture. Professor Storer’s work entitled “Chemistry in some of its relations to agriculture,” the first edition of which was published in 1887, has had a marked effect upon agriculture in this country.

As early as 1846 Yale University, then called Yale College, appointed a professor of agricultural chemistry. This was John Pitkin Norton, who had devoted himself to the study of scientific agriculture both in this country and Europe, especially with the celebrated Liebig. He brought to his position a ripe knowledge and wisely directed enthusiasm for agriculture, which he used with the greatest profit in its service. In 1855 Samuel William Johnson was appointed instructor in agricultural and analytical chemistry, and soon after full professor. Perhaps no one ever succeeded more fully in popularizing scientific agriculture than Professor Johnson. His two books, “How plants feed” and “How plants grow,” the first editions of which were published in 1868 and 1870, respectively, have been kept abreast of modern progress in successive editions, and are still used as standard
text-books and as authorities on the practical relations of chemistry to agriculture.

In the University of California the work of Prof. E. W. Hilgard must be mentioned as being of fundamental importance in the development of the relation of chemistry to agriculture in this country. Professor Hilgard in his classical work on soils has placed himself in the front rank of investigators on this subject, not only in this country but in the world, and his achievements have been recognized both by his countrymen and by the most celebrated societies of Europe. A knowledge of the soil and its relations to plant growth constitutes one of the fundamental principles of chemistry, and the researches of Professor Hilgard in this line have done much to place agriculture in the United States on a strictly scientific basis.

At Cornell, even before her doors were open to students, a professorship in agricultural chemistry was established. Prof. G. C. Caldwell was appointed to fill this position, and he has done so with distinction to himself and the university, and with the greatest benefit to agriculture. One of the most important services in connection with Professor Caldwell's labors at Cornell has been the publication of his work on agricultural chemical analysis in 1869. At that time no work of a similar nature existed in the English language, and Professor Caldwell's book was a veritable boon to students in agricultural science.

This brief reference to the contributions of some of the earlier workers in agricultural chemical science in this country would not be complete without mention of the labors of Prof. C. A. Goessmann, of the Massachusetts Agricultural College.

It is not possible in the space assigned to this paper to even name the more prominent later workers.

A national epoch in agricultural education in this country began with the passage of the Morrill Act, in 1862, establishing and endowing colleges where agriculture should be one of the principal branches in which instruction is given. An additional impetus was given to this great work in 1887 by the passage of the Hatch Act, establishing agricultural experiment stations in the several States. The organization lists of the agricultural colleges and experiment stations of the United States now show the great number of men working in the lines of agricultural chemistry. This most remarkable evolution of agricultural education has taken place practically within the last thirty years, and there is no country which can now be compared with the United States in the munificence of the endowment for agricultural chemical research or in the vast amount of research and experimental work conducted in these lines.
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DISSEMINATION OF THE PRINCIPLES OF AGRICULTURAL CHEMISTRY THROUGH THE AGRICULTURAL PRESS.

One of the important channels through which the principles of agricultural chemistry have been disseminated throughout the United States has been the agricultural journals. In no other country has the agricultural press obtained so firm a hold and exercised such an authority as in this country. Early in the century agricultural journals were established, many of which are still in existence. In 1845 it is stated in the agricultural report for that year that there were twenty-six journals in the United States devoted exclusively to agriculture. Of these, eight were weekly, sixteen monthly, one quarterly, and one unclassified. Among those which are still in existence, and which were mentioned at that time, may be cited the Maine Farmer, the Boston Cultivator, the Massachusetts Ploughman, the American Agriculturist, the American Farmer, the Indiana Farmer, the Prairie Farmer, and perhaps a few others. A list of the agricultural journals of the present time would show a wonderful increase in number. In addition to the purely agricultural journals, a great many of the newspapers of the country have agricultural departments which, at least once a week, convey to the farmer important information in regard to scientific agriculture. It is evident, therefore, that many of the beneficial effects of chemical research relating to agriculture have found their application through the columns of the journals mentioned.

PROMOTION OF SCIENTIFIC AGRICULTURE BY THE ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS.

It is evident that one of the most important ways in which chemistry can promote the interests of agriculture is by furnishing reliable and accurate means of studying soils, agricultural products, and other bodies connected with the interests of farming. If researches of this kind are not made in a uniform way, they can not be compared among themselves, and if they are not made by accurate methods may lead to erroneous results. The full benefit of chemical research, therefore, on agricultural progress can only be secured when the methods of investigation employed are uniform and accurate. The condition of the methods of agricultural research in the United States up to within twenty years was not satisfactory. With the exception of the book by Professor Caldwell on "Agricultural chemical analysis," no distinctively American work had been done along these lines. To Professor Caldwell, scientific agriculture owes a great debt for being the first in this country to attempt to systematize the methods of chemical research as applied to agriculture. Nevertheless, this work had no official authority, and chemists engaged in agricultural research could use the methods described by Professor Caldwell or not, as they saw fit. The first steps toward correcting this condition of affairs were
taken by the department of agriculture of the State of Georgia. Mr. H. J. Redding, now director of the experiment station of that State, induced Hon. J. T. Henderson, commissioner of agriculture of Georgia, to call a meeting of chemists interested in agricultural research, which was held in Washington City, at the Department of Agriculture, beginning July 28, 1880. This initial meeting, after making important advances, adjourned to meet in connection with the American Association for the Advancement of Science in August of the same year. An organization was perfected at this time, and it was again decided to meet with the American association in August, 1881, at Cincinnati.

Methods of analysis were agreed upon at these meetings, which, however, still lacked any official authority, as no permanent official organization had been effected. After the Cincinnati meeting no efforts were made to continue the meetings of the new organization, and it was felt that the personnel of the meetings had been of such a character as to render impracticable a harmonizing of the different conflicting elements represented. No further attempts, therefore, were made to coordinate the work of agricultural analysis until 1884, when a meeting of chemists connected with official agricultural work was held in May, at Atlanta, Ga. Here a strong organization was effected, and the meeting adjourned to Philadelphia in September. At the September meeting the organization of Official Agricultural Chemists was completed, admitting to full membership in the society all persons officially connected with agricultural research of a chemical nature throughout the United States, and to limited membership other chemists interested in agriculture having no official position. The constitution of the association provided that all methods of analysis which were adopted as official, and thus made binding upon its members, should be acted upon only by the votes of those who had official connection with chemical work, under government, either national or State. Since September, 1884, the Association of Official Agricultural Chemists has held annual meetings, mostly in Washington City, and, as a result, methods of research have been perfected and adopted which are made binding upon the members, and which have been recognized by the courts of the country as official in every respect. These methods of research have become so perfect and so effective that they have recognition in all countries, and the work of the association is everywhere recognized as being of the highest order and as having secured the greatest good. At the present time the official methods of investigation include not only the study of soils, of fertilizers, and of agricultural products, but special methods have been adopted for the study of human and animal foods, of dairy products, of different fertilizing elements, of manures and fertilizers in general, of carbohydrates and nitrogenous bodies, of tanning materials, and of insecticides.
The association has not contented itself with the mere study of analytical detail, but has instituted lines of research having for their object the elucidation of unsolved problems in agriculture and the application of the results to practical work. The direct practical benefit of the work of this association has been found in the establishment of efficient fertilizer control in nearly all of the States of the Union. By means of this official control the farmers are protected in the character of the fertilizing materials which they buy. These materials are inspected by the State authorities, and can only be sold when their composition comes up to the standard set by these authorities. The economical value of this control alone is only to be measured by millions of dollars. The association has published the results of its labors in numerous bulletins under the patronage of the Secretary of Agriculture and issued from the Division of Chemistry. These bulletins contain not only the proceedings of the association, with all the discussions relating to problems in practical agriculture, but also recommendations as to methods of research to be followed by chemists throughout the country, whether having relation to agricultural research or not. One of the most important of the works which has been undertaken, and which is now partially completed, has been in determining the standards of purity for food. The work of the Division of Chemistry in respect to food adulteration is described further on. In order, however, that a competent control of food adulteration may be exercised, it is necessary that the judicial authorities have reliable standards to which reference can be made in legal proceedings. It is evident that such standards can only be secured by the comparison of a vast amount of chemical data and an institution of the most careful research. The Association of Official Agricultural Chemists has taken up this subject in a systematic manner, and the various problems relating to the standards of pure food are placed in the hands of special committees, who have already accomplished a great part of the work which has been assigned to them. At the completion of the work it will be possible to present for the approval of Congress, and of the various legislative bodies of the country, a system of food standards, just and correct, based upon the widest knowledge and the most careful research. With the aid of these standards the enforcement of pure-food laws will be made easy and the punishment of those who violate their provisions rendered certain. The proceedings of the association and the methods of analysis and research adopted by them are found in the bulletins issued from the Division of Chemistry.

CHEMISTRY IN AGRICULTURAL REPORTS OF THE PATENT OFFICE, ETC.

NUTRITION.

The first work of agricultural chemistry was naturally to develop the principles upon which plant nutrition is based. It was soon seen,
however, that animal nutrition rests upon the same general principles, and that the same methods of research, with the necessary modifications for the changed environment, are to be used in both cases. Thus early the aid of chemistry was invoked in establishing the true principles of animal feeding. But little was known of a positive nature in this matter in the early parts of the century. Toward the middle of the century, however, considerable contributions had been made by agricultural chemists to this subject. The Agricultural Reports of the Patent Office in early years contained articles on this subject. In the report for 1849 several pages are given to the discussion of the nutritive value of foods. The comparative value of the whole flour of wheat as compared with the fine flour is also given, and the contributions of Peligot, the celebrated French physiological chemist, are freely referred to. An interesting chapter is also contributed on the nutritious properties of various other articles of food, and the chemical methods which were in vogue for determining the composition of wheat flour and of ascertaining its nutritive value are set forth in some detail. The work of the Department of Agriculture in regard to the principles of nutrition has been prosecuted with more or less vigor by chemists connected with its service from the middle of the century to the present time. In the agricultural experiment stations also the principles of animal feeding have been fully developed by practical work. The general principles of animal nutrition were made available for farmers' use at an early day by the publication of Armsby's "Manual of cattle feeding," in the year 1880. Although this was essentially a translation of a foreign work, yet in its publication various improvements and additions were made by the author and translator, which rendered the book far more valuable than the original work. Among the later publications on the same subject may be mentioned the work of Professor Henry, published in 1898. In addition to this, various bulletins from the Division of Chemistry and from the Office of Experiment Stations of the Department of Agriculture have been issued from time to time on the subject of nutrition and on the composition and nutritive value of foods in general.

As the result of all these investigations the practical farmers of the country have now at their command, and in forms which they can fully understand, the great principles of animal nutrition. It is certain that the actual cost of the food required for placing an animal upon the market for meat or in preparing it for work has been very much diminished. Even if no further progress were made in the science of nutrition, the economic results which have been obtained in this line would be a sufficient justification for all the expenditure of money, time, and labor which has been incurred in the progress of agricultural chemistry up to the present moment. While it is doubtless true that many great discoveries are yet to be made in the domain of the science of nutrition, yet enough is now known to illustrate fully
the circle of life beginning with the inorganic matters in the soil, in
the air, and in the water, passing through the organism of the plant,
and reaching the highest form of organized matter in the living animal.
The investigations in nutrition have even gone further than this, and
show how the elements of food, both for plants and animals, after
having served their complete functions in one or the other of these
organisms, or in both, are preserved intact, to be returned to the
original condition of mineral substances in the soil, in the air, and in
the water, to begin anew the circle of life. The present era, there-
fore, finds established as definite scientific principles the prescient
predictions of the great Lavoisier concerning the methods of plant
and animal nutrition.

DANGER OF EXPORTING PLANT FOOD.

The work done in the Division of Chemistry, as well as by agricul-
tural chemists in other parts of the country, has called attention to
the danger of unlimited exportation of food products containing large
quantities of plant food. In fact, early in the history of the Depart-
ment of Agriculture attention was called to this matter. In the Agri-
cultural Report of the Patent Office for 1849 mention is made of the
fact that prior to 1846 Ireland was an exporter of large quantities of
cereals, sending abroad more of them than the whole of the United
States. Much of the grain sent from Ireland was oats. The exhaust-
ing effect of cropping a field to oats is known to all practical farmers,
and to this is attributed the fact of the subsequent failure of the crops
in Ireland and the great suffering due to the famines caused thereby.
An elaborate report on the subject of exporting plant food was pre-
sented by the present chief of the Division of Chemistry in his address
before the American Association for the Advancement of Science in
the Buffalo meeting of 1886. In this report the quantities of plant
food removed by the crops from the fields of the United States annu-
ally were set forth. The value of plant food lost at that time by ex-
portation of farm products was, by a careful computation, found to be
over $33,000,000 per annum. Since that time the exportation of farm
products from this country has almost doubled, so that at the close of
the century it is safe to say that the value of the plant food, calculated
from a manurial standpoint, lost by exportation from the United
States is not far from $70,000,000 per annum.

This subject was more fully developed in an address delivered before
the American Chemical Society on December 27, 1893, at the Boston
meeting. While it is true, as illustrated in these addresses, that the
quantities of plant food lost by exportation are less than by other
causes, nevertheless the danger of exhausting the fertility of fields
by the continual sale of agricultural crops is fully understood. Chem-
ical researches in the Department of Agriculture and in other parts
of the country have established this principle beyond peradventure,
and have taught the farmers of the United States that one of the surest methods of retaining the fertility of their soil is to feed as much as possible of the crops produced at home. The home feeding of domesticated animals secures a large part of the value of the food in the form of manure, and this tends to diminish the rate at which otherwise the fertility of the fields would be exhausted. Chemistry has shown that there are certain products of the fields, however, which can be exported or sold with no loss in fertilizing materials. Among these may be mentioned starch, sugar, cotton, and oils and fats of every description. These bodies, contrary to the views held at the beginning of the century, are now known to have no value whatever as plant foods, and hence can be sold from the farm with impunity. It is true that no system of farming can be devised which will absolutely prevent the removal of certain quantities of plant foods in the crops; but scientific agriculture, founded upon chemical investigations, will lead farmers to that course of practical economy which will bring to a minimum the loss of fertility from this cause.

RESEARCHES ON DAIRY PRODUCTS.

The importance of the chemical composition of the dairy products was early recognized in the chemical work of the Department of Agriculture, and the Agricultural Report of the Patent Office for 1849 contains an article on the chemical properties of milk and butter. The research work of the Department on these products has been continued at intervals since that time, and important publications devoted to this subject have been issued. The Division of Chemistry, since the establishment of the Bureau of Animal Industry, has cooperated with that Bureau in the study of dairy products from a chemical and physiological point of view, and this cooperation is still continued.

IMPROVEMENT OF WORN-OUT LANDS.

Special researches have been made in the Division of Chemistry of the Department of Agriculture on the methods of improving worn-out lands. Early in the history of the Department this study was recognized as an important one, and an article is found in the Agricultural Report of the Patent Office for 1849 on the improvement of worn-out lands by the use of peas and clover. At intervals since then this subject has received the attention of chemical research, not only in the Department but in other parts of the country. A bulletin on the subject of the reclamation of worn-out lands was issued in 1894, a large part of which was contributed from the Division of Chemistry. The researches which the agricultural chemists have made, in collaboration with other scientific work of a botanical and mechanical nature, point out the way whereby lands which have been deprived of the greater part of their fertility and otherwise exhausted by culture may be restored to a high degree of fertility. In many
parts of the United States are found abandoned fields and even farms, since it has been found more profitable to search for new and fertile soils than to develop and restore old and worn-out fields. At the present time, however, the area of virgin fertile soils is practically exhausted, and the attention of scientific agriculture is now directed with more energy than ever to the restoration of the fertility of soils long since abandoned. It is certain that in the near future the practical farmer, with the aid of chemical research, will effect the restoration of the greater part of the agricultural lands of the United States, which have heretofore been abandoned to briars and brush, to their natural position as fertile and profitable fields.

CHEMISTRY IN THE DEPARTMENT OF AGRICULTURE.

Perhaps there is no other method in which the researches of chemistry have been made practical for agricultural purposes in a more general way to the agriculture of the United States than through the work of the Department of Agriculture. So long as the work of the Department was conducted in the Patent Office, chemical investigations of agricultural subjects continued to be the chief scientific inquiry.

ANALYSIS OF GRAINS AND OF FLOUR AND MEAL MANUFACTURED FROM THEM FOR EXPORTATION.

The first appropriation in this country for purely scientific services in agriculture was made at the first session of the Thirtieth Congress, when $1,000 was given "for the institution of a system of analyses of different grains produced in this country and of flour manufactured here and exported abroad."

The important problems which it was sought to solve in these investigations were the effect of soil and climate upon the different varieties of grains and the effect of a sea voyage and storage upon the flour and meal manufactured from grains produced here and sent abroad.

Prof. Lewis C. Beck, of Rutgers College, New Brunswick, N. J., an experienced analytical chemist, was employed to conduct the chemical work. The Commissioner of Patents made efforts to receive samples of wheat, Indian corn, and flour from the ports of the most distant countries to which they had been exported. Professor Beck's report is made an appendix to the Agricultural Report of the Patent Office for the year 1848. Professor Beck, in introducing his report, enters into an elaborate discussion of the economic relations of chemical studies to agriculture. He states that in 1847 breadstuffs worth $43,000,000 were exported from this country to Great Britain and Ireland alone. He is of the opinion that the best method of determining the real value of wheat and other flours is to examine the bread made from them, and calls attention to the fact that chemicals
are used in some countries in the manufacture of bread in order to conceal the defects of the flour from which it is made.

In Belgium and the north of France it is stated that sulphate of copper has been introduced into the manufacture of bread, and that the use of alum has been practiced from a remote period. In addition to these, the alkaline carbonates, the carbonate of magnesia, chalk, pipeclay, and plaster of Paris have all been employed in the manufacture of bread from inferior or damaged flour in order to preserve its moisture or to increase its weight and whiteness. Further adulterations of bread are stated to be with potato starch and flour of leguminous plants, buckwheat, and rice, and citations are made to the literature where the methods of discovering these adulterations can be found. Professor Beck quotes largely from Boussingault's "Rural Economy," Dumas's "Traité de Chimie Appliquée aux Arts," and from Davy's "Agricultural Chemistry." The method of analysis employed by him is fully set forth, and the data obtained from the numerous analyses are given, showing the amount of water, gluten, starch, and sugars contained in the various samples. In all, thirty-three samples of flour were analyzed, collected from different parts of the country, and from distant ports to which flour from this country had been shipped.

It is thus seen that several of the most important lines of investigation which have subsequently been followed in the chemical work of the Department were marked out at this early period by Professor Beck. He introduced the first systematic work in determining the character of the cereals of the country, published methods of analysis for the guidance of other chemists engaged in similar work, and began the investigation of the great subject of food adulteration.

A similar work on Indian corn was conducted by Dr. J. H. Salisbury, of Albany, N. Y., and the results of his analyses were published in the report for 1849.

**Establishment of Division of Chemistry.**

In 1862 the Department of Agriculture was organized on an independent basis. In the organic act establishing the Department it is stated that the Commissioner of Agriculture shall "employ other persons for such time as their services may be needed, including chemists, botanists, entomologists, and other persons skilled in the natural sciences pertaining to agriculture."

It is thus seen that chemistry was recognized, by its assignment in the order of mention, as of the first importance in the scientific work of promoting agriculture throughout the country. In accordance with the authority vested in him by the organic act, Isaac Newton, who was the first Commissioner of Agriculture, established the Division of Chemistry by the appointment of Dr. C. M. Wetherill, a distinguished chemist, as the first chief of Division. Dr. Wetherill
was appointed Chemist on August 21, 1862, and served until some time in 1863.

Commissioner Newton, confirming the statement made by Judge Buell more than twenty years before, gave as the first of the scientific objects of the Department "analysis, by means of a chemical laboratory, of various soils, grains, fruits, plants, vegetables, and manures, and publishing the results for the guidance and benefit of agriculturists."1 Of the work of the Chemist for the first year, the Commissioner said:

Fortunately the Chemist to the Department was in possession of an extensive scientific library and apparatus, which he kindly placed at my disposal at the commencement of my duties as Commissioner. The season had so far advanced, however, that but few tests could be made. The Chemist has, nevertheless, analyzed some twenty-two varieties of grapes, and is at present engaged in the examination of ten or twelve varieties of wines, also sorghum from eight or ten different localities, in order to determine the relative value of sirup and its capabilities for producing sugar and molasses, as compared with sugar cane. As soon as arrangements now being made in the laboratory are completed, the Chemist will enter into the analysis of the various grasses and grains of the United States, in order to learn which will produce the greatest amount of fat, flesh, muscle, and bone; also of soils, manures, and the constituents of plants, with especial reference to restoring fertility to exhausted farms.

REPORTS OF THE CHEMISTS.

On January 1, 1863, the first report of the Chemist of the Department of Agriculture was submitted for publication. This report is interesting as the first one on a scientific subject ever made to the Department by a person employed exclusively for the conduct of scientific work. The Chemist's report covers the analysis of grape juices, of sorghum and imphee, the examination of various sugars and sirups, the analysis of beets, and an article on the chemistry of sugar manufacture in general. Thus, at the very outset of the special relations of chemical science to the Department of Agriculture, some of the most important lines of investigation which have since been followed were established. Chief among these may be mentioned the study of the wine-making industry, both from the fermentative and chemical points of view, and the beginning of that study in the chemistry and technics of sugar manufacture, which has since done so much to establish an indigenous sugar industry in the United States.

The Annual Report of the Commissioner for 1863 contains no report from the Chemist of the Department.

The report of the Chemist for 1864 (Mr. Henry Erni?) relates to organic or vinous fermentation, acetic fermentation, butyric-acid fermentation, theories of the origin of mold, or fungi, methods of detecting the artificial coloring matters in wines, the analysis of wines, and the analysis of soils and guanos.

2 Appointed probably July 1, 1864.
The report for 1865 was devoted to the analysis of soils, sugar beets, sorghum and imphee, wines, and miscellaneous work of various descriptions.

In 1866 Dr. Thomas Antisell was appointed Chemist of the Department. His first report was devoted to the analysis of soils and manures, agricultural products, and mineral and metallurgical analyses. During this year also the cooperative work between the Division of Chemistry and other Departments was begun. Dr. Antisell says, on page 45 of the Annual Report: “Besides the foregoing, the laboratory has been engaged with analyses for other Departments of the public service.”

Dr. Antisell, in his report for 1867, enters into an elaborate discussion of the analysis of sugar beets and of the sugar-beet industry, thus having laid the foundation for the extensive developments in the investigations along this line, which have been carried on by the Division of Chemistry for the past thirty years. In order to increase the efficiency of the work of the Division, Dr. Antisell suggested that the scope of its work should be enlarged so as to embrace the relations of geology to agriculture and to include the study of metallurgy. He suggested that geology had intimate relations to agriculture, and advised the establishment of a geological and mineralogical laboratory and museum to illustrate the economical relations of geology to the agriculture of the United States. He says: “Whatever relations of soils to their parent rocks exist would thus be brought out in a prominent and systematic manner.” It will be observed from this reference that the first official recommendation for the establishment of a geological survey emanated from the Division of Chemistry of the Department of Agriculture, as well as the suggestion of the study of meteorology and other matters connected directly with agricultural crops.

In 1868 the chemical laboratory was removed from the Patent Office to the building of the Department of Agriculture, which had just been completed. The report of the Chemist for that year contains a reference to the newly discovered phosphatic deposits of South Carolina, with remarks upon their value for agricultural purposes.

The report for 1869 contains an interesting article on the analysis of soils. The Chemist also urges the establishment of an experimental garden, where the problems involved in chemical research could be studied actually in the field. This recommendation was a reiteration of one previously made by him in the same direction. The importance of practical experimental stations in connection with chemical research is thus early in the history of the work of the Division properly recognized.

The report of the Chemist for 1870 contains an interesting article on the alkaline soils of the West, giving a complete study of their

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1 Appointed probably July, 1866.
physical and chemical properties, especially an account of the determination of the soluble matter in the surface. The first work which had been undertaken on the composition of meat extracts is also discussed in the report, as well as the foods used by the Indians.

The work for 1871 is described by the Commissioner in his report for that year as being memorable on account of the beginning of two extensive investigations. One of these was the analysis of several hundred specimens of cereals carefully selected from the entire production of the country. The other was the examination of the leaf, stem, and fruit of the grapevine during every week of its growth. The Commissioner says: "By this work it is expected that new analogies in animal and vegetable physiology will be established and information gained which bears directly upon the diseases of the vine."

From the earliest establishment of chemical researches in the Department, a large part of the time of the Chemist and his assistants had been taken up with analyses not at all relating to agriculture. Chief among these were the assay of gold and silver ores and the study of samples for commercial purposes for private individuals and corporations. This perversion of the proper functions of the Division of Chemistry had been so pronounced as to warrant the Commissioner to say in the report for 1871: "To enable the Chemist to devote himself to those important subjects in agricultural science which await and demand chemical research, I am strongly of the opinion that the public privilege should be restricted to the employment of the laboratory for such purposes only as relate to agriculture."

In July, 1871, Dr. Antisell resigned the position of Chemist, and on January 11, 1872, Dr. R. T. Brown was appointed to the position. The report of the Chemist for that year emphasized the importance of sodium nitrate as a manure, and the value of the deposits in Peru, Chile, and Bolivia for agricultural purposes is mentioned. Attention is called to the fact that the soils of the blue-grass region of Kentucky renew their stock of phosphatic materials by the decomposition of the limestone rocks, and this observation has in later years been confirmed by the researches of the agricultural experiment station of Kentucky, which show that these soils are never deficient in phosphates, but only in potash and nitrogen. The importance of bone and natural phosphates for fertilizing purposes is more fully brought out in this report than in any previous contribution from the Department, and large numbers of analyses of commercial fertilizers are given.

In 1872 the report was devoted largely to the analysis of commercial fertilizers and sugar beets. An important contribution is also found in this report on the utilization of the wastes of cities and towns for agricultural purposes, a subject which has since received very careful investigation in the Division of Chemistry.

In 1873 Dr. Brown resigned and was succeeded by Dr. William McMurtrie, who held the position until January 2, 1878.
In the first report of Dr. McMurtrie attention is again called to the fact that the Department has been very much troubled with applications for analyses of minerals, ores, commercial products, etc., which have little or no bearing upon agriculture or agricultural chemistry. The work during the first year of Dr. McMurtrie's incumbency was largely devoted to the analysis of wines, fertilizers, and soils. An interesting résumé of the knowledge at that time relating to humus is given, with references to the work of Grandeau on that subject. Another interesting article in this report is a contribution on the approximate composition of cereals, Indian corn being the one selected for study. The first investigation relating to tanning materials was also reported at this time.

The Chemist's report for 1874 includes a report of an investigation of the fodder plants of the South and a study of insecticides, especially Paris green, in regard to their use in agriculture. Reference is also made to the work of Dr. Goessmann, of the Massachusetts Agricultural College, on the culture of the sugar beet. This was the beginning of Dr. McMurtrie's investigations of the sugar-beet industry, which he afterwards carried forward with such success and advantage to American agriculture.

In the work of 1875 the first studies were commenced in chemical processes affecting agriculture by the actual growth of plants. A series of valuable experiments was conducted in the application of insecticides to growing plants. The effects of these insecticides were carefully noted and photographs representing the plants treated were secured and published. Similar experiments were made to show the effects of illuminating gas upon vegetation. This was the beginning of the realization of the recommendations made by Dr. Antisell for the practical investigation of agricultural chemical problems upon the plant itself.

The report for 1876 refers to the part taken by the Division in the Centennial Exposition which was held during that year at Philadelphia.

The work for 1877 is summarized in the report of the Chemist under nine different heads, namely: (1) Analysis of lime marls; (2) examination of soils; (3) analysis of bat guano; (4) analysis of sugar from Early Amber sorghum cane; (5) estimation of the amount of sugar in various beets sent to the Department; (6) the examination and report of an experiment in beet culture made on Batsto farm, Atlantic County, N. J.; (7) experiments to determine the presence or absence of the so-called peptone-forming ferment in the roots of plants; (8) investigation of American sumac; (9) investigation of the physical and chemical causes tending to the production of mildew and rot. The latter investigation is interesting from the fact that it indicates that the first beginnings of studies of this kind were established in the Division of Chemistry.

At the beginning of 1878 Dr. McMurtrie resigned to accept the
Deceased Chiefs of the Division of Chemistry.
position of representative of the Department at the international exposition to be held at Paris during the year, and January 22, 1878, Dr. Peter Collier was appointed Chemist in his stead.

The first report of Dr. Collier covers the beginning of the work conducted by him on the production of sugar from Indian-corn stalks and from sorghum. While, however, during this first year only 8 samples of these sugar-producing plants were examined, 57 sugar beets were analyzed. A joint report of the Botanist and Chemist on grasses and forage plants, issued January, 1884, is interesting as showing, in an ideal way, the methods in which the different scientific Divisions of the Department may collaborate in advancing the interests of agriculture. Dr. Collier held the office of Chemist until April 9, 1883. During this time a large part of the activity of the Division of Chemistry was devoted to the study of sorghum as a sugar-producing plant, and the most extensive series of analyses ever instituted up to that time for agricultural purposes was conducted under his direction.

The reports prepared by Dr. Collier on this matter and appearing in the several annual reports deal with every phase of the subject, chemical, agricultural, and technical. The high price of sugar at this time excited the interest of investors in the subject of the practical manufacture of sugar from sorghum, and a large amount of capital was placed in this business. Unfortunately for the sorghum industry, the rapid development of the beet-sugar industry in Europe brought into competition with sorghum a sugar-producing plant which, under the impetus of careful chemical study and technology, rapidly produced a surplus of sugar in the markets of the world, causing an unprecedented fall in price. The difficulties attending the manufacture of sugar from sorghum, due to the chemical composition of the plant, were not solved with sufficient rapidity to enable sorghum to remain as a competitor for supplying the sugar markets of the world. As a result of this combination of economic, chemical, and technical causes, the production of sugar from sorghum never became profitable. While, as stated, the study of the sugar problem was the main work of the Division of Chemistry during the incumbency of Dr. Collier, other matters, relating to agricultural industries were not neglected. The study of soils and fertilizers was continued without intermission, and the foundation was laid for the systematic study of cereals, which afterwards became so important a part of the work of the Division.

The portraits of the deceased chiefs of the Division of Chemistry are given in Pl. V.
Since April, 1883, the work of the Division of Chemistry in its relation to the progress of agriculture has been directed chiefly along the following lines:

*Study of sorghum.*

The study of sorghum as a sugar-producing crop was continued with the special object of overcoming, if possible, the difficulties which had stood in the way of a successful industry. At first the work was more of a chemical and technical nature, looking to the establishment of methods to secure more economical working and larger yields. To this end, the diffusion process of extracting the sugar from the canes, which had been so successfully used with beets in Europe, was applied to sorghum with such modifications as the different nature of the material required. An increase in the amount of sugar extracted from the canes was easily obtained, but the greatest difficulty in the way of successful sugar making still remained, namely, the chemical composition of the extracted juices. It was found that the juices extracted from sorghum canes contain large quantities of starch, gummy matters, and uncrystallizable sugars. These existed in such large proportions as to render the separation of the sucrose in large quantities practically impossible. Various chemical methods of removing these impurities were devised and applied. Among them, the two which promised most success were the process of saturation with lime, or carbonatation, as practiced with beet juices, and the removal of the starchy and gummy matters by precipitation with alcohol. The former method, after a thorough trial, was abandoned as impracticable. The latter method resulted in a complete success, yielding with canes of average composition 200 pounds of sugar per ton. The fiscal regulations covering the production and use of alcohol in this country, however, were of such a nature as to render the use of this reagent impracticable from an economical point of view without some change in the excise laws of the country.

Meanwhile other investigations were carried on with great success; among them the process of developing a variety or varieties of sorghum in which the objectionable qualities would be reduced to a minimum and the percentage of sugar raised to a maximum. This desirable end was accomplished by a series of culture experiments in cooperation with Mr. A. A. Denton extending over eight years, in which, by a process of selection, both from the point of chemical composition and from physical qualities, several varieties of sorghum were developed, which were far superior to any which had before been known. It was established by the researches of the Division that fields of sorghum could be grown having an average sugar content of 14 per cent and with a much higher purity than characterized the parent canes from which the varieties were derived.
In spite of all the progress made, however, it was found that the increasing competition of sugar derived from the sugar beet had decreased the price of sugar in the world's markets, until it would not be profitable to manufacture sugar from sorghum, even under the more favorable circumstances which obtained. But the final results of these investigations were not without their practical value, as the utility of sorghum as a source of table sirups and as a cattle food was fully developed and established. It was also shown that in the semi-arid regions of the country, where the practice of irrigation was not possible, there is no crop which is so certain to bring a remunerative yield as sorghum when cultivated in the proper manner.

The final result of the work conducted by the Division over a period of more than twenty years on sorghum as a field crop has established its status as one of the most remunerative plants when cultivated in certain areas of the country. In fact there is scarcely any part of the United States where sorghum is not cultivated, and even in Minnesota the finest table sirups which are found upon the market in that region are made from one of the early varieties of sorghum cane which grows to maturity in the short summer seasons of that State.

*Study of cereals.*

Another line of investigation which has been carried on extensively during the past seventeen years has been a study of the composition of the cereals of the United States. This work, it is true, as has been stated, is only a continuation of the very first scientific work authorized by the Government when the Department was still a section of the Patent Office. The opportunities, however, for the use of more accurate means of analysis and to secure samples grown under different conditions, from more widely separated areas, have made the continuation of this study one of the most profitable for the advancement of agriculture. The bulletins which have been issued on this subject embody the results of many thousands of analyses, and show with greater fullness and accuracy than any other publications which have been issued the variation of cereal products under different conditions of soil and climate. The successful work of improving a plant by selection and taking advantage of natural variations, as illustrated in the case of sorghum, has now been applied to the study of cereals. The causes which produce variations are under investigation, and also the methods for improving the composition of cereals with reference to certain of their more valuable constituent parts. For instance, the percentage of gluten in wheat is of the utmost importance to the bread maker, since it is this body which gives to wheat flour the physical characteristics that render it more valuable than that from other cereals for bread-making purposes. Under the varying conditions of soil and climate in this country it is found that the content of gluten in wheat changes. The utmost practical advantage, therefore, will
come to the wheat grower from a practical study of this cause and suggestions of the best methods of preserving or increasing the content of gluten in wheat.

The broad principle has been established that, other things being equal, wheats from a high northern latitude contain more gluten than those grown farther south and the wheats that are sown in the spring a larger quantity of gluten than those which are planted in the autumn. It is believed, however, that a careful chemical study of this subject in connection with the proper study of meteorological conditions will enable wheat growers to largely increase the content of gluten in the autumn-grown and southern wheats.

Study of food adulteration.

The practice of adulterating human foods, which has been so largely prevalent in all parts of the world, has proved of incalculable injury to honest agriculture. The value of scientific farming in its ultimate measure is determined by the benefit which accrues therefrom. If the returns from scientific farming prove to be less than those from unscientific methods, the latter will certainly prevail. The markets for farm products must therefore be preserved with as much care as the fertility of the fields. The sole object of food adulteration is to enable the unscrupulous manufacturer or dealer to sell an inferior article at the price of a superior. Food adulteration, therefore, which totally changes the aspect of the food of an inferior kind so that it does not at all resemble the superior kind would defeat its own purpose. Every pound of adulterated food which is sold upon the market at the price of the genuine article or at a price approximating thereto is a positive injury to agriculture, since it excludes from the market an equal quantity of farm products of a genuine character. Thus, the practice of food adulteration directly diminishes the profits of the honest farmer and dealer.

Much of the activity of the Division of Chemistry during the past seventeen years has been directed to a study of the methods and character of food adulteration with a view to devising proper legal restrictions for its prevention. To this end a large part of the scientific corps of the Division has been assigned to a systematic study of the adulteration of foods, and the results of these studies have been published in numerous bulletins relating to that subject. The object of these studies is to finally cover the whole range of food production, and this has already been largely accomplished.

As an illustration of the way in which adulterated foods may injure the farmer’s profession may be cited the sale of oleomargarine for butter and glucose for honey. The food value of oleomargarine and of glucose is not denied. They are, however, very much cheaper products than butter and honey. These adulterated foods, unfortunately, are often not offered for sale under their own names, except by legal
compulsion, but are placed upon the market under the names of the genuine articles which they are manufactured to imitate. Buyers, therefore, pay, as a rule, prices which would be asked for the pure articles. The market for the pure articles is diminished just to the extent to which these other substances are sold, and in this way positive injury to great agricultural interests is done. The chemists of many of the agricultural experiment stations throughout the country have collaborated with the Division of Chemistry in these studies, so that the whole subject of food adulteration is pretty thoroughly understood and its extent acknowledged. Many of the legislatures of the States have already enacted restrictive measures regulating the sale of adulterated foods, and bills have been before the Congress of the United States having the same object in view. The work in which the Division of Chemistry was a pioneer has commended itself to the people at large, and through the press and before farmers' institutes full descriptions of the methods and character of adulteration have been disseminated among the people. Public opinion has been so aroused on this subject as to demand of the National Legislature the enactment of laws regulating commerce in adulterated foods in the Territories of the United States and between the several States thereof. The work of the Division has therefore already secured great benefits to agriculture in the way of preserving an honest market for the products of the farm, and made it possible for these benefits to be greatly increased by favorable national legislation on the subject.

Comparative studies of soils.

For the past seventeen years the Division of Chemistry has continued its researches in the study of the soils of the United States. Before the organization of the Association of Official Agricultural Chemists, and for the benefit of agricultural chemists throughout the country, a bulletin was prepared giving the results of soil studies and a summary of the best methods known at the time for conducting them. In order to study comparatively typical soils special authorization was obtained from Congress for the establishment of a vegetation house in which soils from different parts of the country and even from foreign countries could be studied under similar conditions in respect of their powers of producing organic matter and in their relations to nitrifying organisms. In no other way can the relations of different soils from the point of view of their chemical and physical composition in producing crops be so definitely determined. A knowledge of the soil is the fundamental structure on which agricultural chemistry is built. While in all parts of the world numerous experiments have been carried on to determine the relative value of fertilizing principles on plant growth, it is believed that the comparative determination of native soil fertility under standard meteorological conditions has first been studied in
this Division. The great problem of human nutrition is to find its only solution in the maintenance or increase of soil fertility, and hence every study of this kind which tends to give additional knowledge regarding the cause of fertility and the means whereby it can be maintained, is of the highest economic importance. The complete triumph of agricultural chemistry will be realized when with increased crops shall be found increased soil fertility.

The system of agriculture which has so largely prevailed in this country of exhausting the fertility of one field and then moving the farm to another has come to an end. Scientific agriculture now retraces its steps and restores the fertility of the abandoned fields while it prevents the exhaustion of those which are still productive. Agricultural chemistry in its fullest development will only ask of nature to furnish meteorological conditions and a place on which to plant the crops. Even these will be modified and changed to suit the demands of the agriculture of the future, for it is certain that by the proper manipulation of the soil and the addition of proper chemical fertilizers the capacity for retaining moisture for use in seasons of drought or for disposition of excessive moisture in seasons of rains will be greatly increased. With a wise disposition of the water at his command, the scientific farmer of the future will cultivate millions of acres which are now regarded as hopelessly arid, and recover from the excess of water other large areas now abandoned to swamps and marshes. In these scientific studies of soil composition and soil possibilities with relation to the composition of plants and to increased fertility will be found in the future, as has been the case in the past, some of the most notable triumphs of agricultural chemistry.

In connection with these soil studies, there has also been made a systematic study of the nitrifying organisms through whose agency organic and atmospheric nitrogen become available for plant food. A practically new system of soil analysis has been inaugurated by which it is possible to determine both the number and activity of the nitrifying organisms contained in a sample of soil. These researches are of the greatest practical benefit in agriculture, since they show how the number and activity of nitrifying organisms can be increased, and thus the availability of the nitrogenous food of plants be enhanced. An outline of the relations of these studies to practical agriculture has been prepared for this paper by the first assistant of the Division of Chemistry, Mr. E. E. Ewell.

RELATION OF MICROORGANISMS TO NITROGEN NUTRITION OF CULTIVATED PLANTS.

EARLY STUDIES OF MICROORGANISMS AND NITROGENOUS PLANT FOOD.

The development of the prevailing opinions relative to the rôle of the microorganisms in the preparation of the nitrogenous food of our cultivated plants is a long story. Indeed, its beginning may be
traced back to the closing years of the eighteenth century (1770 to 1800), during which period the labors of Black, Scheele, Priestley, Lavoisier, Cavendish, Watt, Ingenhousz, Senebier, and Woodhouse established the chemical nature of the constituent gases of the atmosphere—nitrogen, oxygen, carbon dioxide, and water vapor—and began the study of the relation of these substances to vegetable growth. Early in the present century De Saussure materially advanced the knowledge of the processes by which the carbon dioxide and the water of the atmosphere and of the soil are converted into vegetable tissue, and expressed the opinion that the nitrogen therein contained was obtained from the compounds of that element found in the soil and in the air; but the relation of atmospheric nitrogen to vegetation remained obscure until within two decades of the century’s close.

Boussingault devoted a considerable part of twenty years (1837–1858) to the study of this question. His experiments seemed to show conclusively that plants are unable to use the free, uncombined nitrogen of the air for the construction of the nitrogenous bodies which form parts of their tissues, and that their nitrogenous food is exclusively drawn from nitrogen compounds contained in the soil.

The experiments of Yille (1849–1854) led to precisely the opposite conclusion. In 1854, appreciating the importance of the subject, the Academy of Sciences of France appointed a commission, consisting of Dumas, Regnault, Payen, Decaisne, Peligot, and Chevreul, to observe and report upon a repetition of these experiments to be conducted by Yille, with the assistance of Cloez, in the Muséum d’Histoire Naturelle. In 1855 Chevreul reported on behalf of the commission “that the experiment made at the Muséum d’Histoire Naturelle by M. Yille is consistent with the conclusions which he has drawn from his previous labors.”

Messrs. Lawes and Gilbert, at their now famous experimental farm at Rothamsted, England, have devoted much time to this question since 1857. Their earlier experiments (1857–1860) were negative for both leguminous and nonleguminous plants, thus contradicting the results of Ville and confirming those of Boussingault.

Two of Boussingault’s experiments, made 1858–59, seemed to indicate that free nitrogen had been brought into combination either by some lupine plants or by the rich garden soil in which they were growing. He did not accept these results as evidence of the assimilation of nitrogen by plants, however, as is indicated by the following from his letter to Gilbert, dated May 19, 1876:

As for the absorption of the gaseous nitrogen of the air by arable soil, I know of not one single irreproachable observation that establishes it. Not only does the soil not absorb gaseous nitrogen, but it emits it, as you and Mr. Lawes have observed, as Reiset has found in the case of manure, and as Schloesing and I have noted in our researches on nitrification. If there is a perfectly demonstrated fact in physiology, it is that of the nonassimilation of free nitrogen by vegetation, and I may add by the lower plants, such as the mycorrhizas and fungi.
Many other investigators devoted much time to this question between the years 1850 and 1886: Cloez and Gratiolet, 1850-1855; Méne, 1851; Petzholdt, 1852-53; Wolff, 1853-1886; Hasting, 1855; de Luca, 1856; Dehérain, 1875-1885; Berthelot, 1876-1886; Atwater, 1883-84; Dietzel, 1884; Joulie, 1885; Frank, 1886.

This long series of experiments, covering more than half a century of time, were contradictory, one of another, erroneous in conception in some cases, and erroneous in manipulation in others, while the conclusions drawn from them were correspondingly inaccurate and incomplete. The most fruitful source of wrong conclusions was, however, to be found in the fact that in the zeal of many of the workers to deprive their experimental soils of compounds of nitrogen they so treated them as to destroy what we now know to be the potent factor in the assimilation of free nitrogen by plants—the microorganisms which form the nodules upon the roots of leguminous plants and thereby enable the plants of that order to indirectly draw upon the atmospheric store of uncombined nitrogen. Attention had frequently been drawn to these peculiar nodular structures on the roots of clover, lupines, beans, etc., notably, by Lachmann in 1858, by Berkeley in 1863, and by Rautenberg and Kuehn in 1864. Indeed, it was suggested by some of these writers that possibly the nodules were connected in some way with the taking in of nitrogen by the plants. It came to be a well-established fact that there was a something that distinguished the manner of the nitrogen nutrition of leguminous plants from that of other plants. They were found to contain more nitrogen than it seemed possible for them to obtain from the combined nitrogen of the soil and the atmosphere in which they grew.

**Work of Bacteria in the Soil in Supplying Nitrogenous Food for Leguminous Plants.**

At the Berlin meeting of the agricultural section of the Naturforscher-Versammlung, September, 1886, the late Professor Hellriegel read a paper disclosing results which have revolutionized our ideas relative to the nitrogen nutrition of plants, and which show the mistakes and the blindly groping nature of the experiments enumerated above. This paper throws a flood of light upon the path to be followed by practical agriculturists in the future. In short, Professor Hellriegel proved by evidence which has been accepted by the entire scientific world that the root nodules of leguminous plants are caused and inhabited by a species of bacteria; that these bacteria, by their symbiosis, enable the plants to indirectly feed upon the practically unlimited and costless store of free nitrogen, which forms eight-tenths of the earth's atmosphere. True, clover and other leguminous plants had previously been valued as soil renovators, but we are now able to use them with an understanding and a confidence hitherto impossible; with the hope that by their use as green manure, as food for
farm animals, and as a source of merchantable produce, we may main-
tain the fertility of our fields, in so far as the element nitrogen is
concerned, without the costly use of artificial nitrogenous manure,
the nitrogen compounds of which will thereby be preserved for other
industrial needs.

There is still some investigation needed to determine the most cer-
tain and economical methods of insuring an abundant supply of the
nodule bacteria in soils on which leguminous crops are to be grown.
Nobbe and Hiltner have secured patents for the manufacture and the
use of pure cultures of several varieties of nodule organisms. These
cultures are prepared on a commercial scale in Germany and placed
on the market under the name of "Nitragin, a germ fertilizer for
leguminous crops." The value of these preparations has been inves-
tigated by the experiment stations of Europe and of this country, but
the results thus far obtained are conflicting.

WORK OF BACTERIA IN SUPPLYING NITROGENOUS FOOD FOR PLANTS IN GENERAL.

We have to this point only mentioned the microorganisms that par-
ticipate in one method of nutrition of the leguminous plants. We
have yet to consider those microorganisms which are active in the
preparation of the nitrogen compounds on which plants in general
feed, including leguminous plants growing without the assistance of
the nodule bacteria. It now appears well established that combined
nitrogen, chiefly in the form of nitrates, is practically the sole
nitrogenous food of agricultural plants in general.

It is to be noted, however, that a method for enabling nonnitroge-
nous plants to draw their supply of nitrogen from the atmosphere has
been brought to the attention of agricultural scientists during the
last decade. The cultures of the organism for which this property is
claimed are manufactured in Germany and sold under the name of
"Alinit." The experiments which have hitherto been made with
"Alinit," as an agent for soil inoculation have not confirmed the
claims of Caron, the German agriculturist, who discovered the Bacill-
us ellenbachensis a, the organism contained in "Alinit," and the
interesting properties with which he credits it. There is, however,
some experimental evidence, obtained in the laboratory, which is
more favorable to it.

Since we must furnish our agricultural plants in general with an
abundant supply of nitrogenous plant food, chiefly in the form of
nitrates, there is no more important question in agricultural science
than that of the manner in which this is to be done with certainty
and with the greatest economy. Although the judicious introduction
of leguminous plants into our systems of crop rotation and stock
feeding may make the farmer independent of the dealer in commer-
cial nitrogenous manures, it is still necessary to study with earn-
estness the methods by which the supply of crude nitrogenous
compounds contained in barnyard manures and in crop residues are to be transformed into nitrates speedily and with the least possible loss.

It has long been a common experience that straw, manures, etc., when incorporated with arable soil, are found to have disappeared after some weeks or months, and that crops planted on the soil so treated grow more luxuriantly than upon adjoining unmanured land. The agencies by which organic matter is thus destroyed and changed into plant food were not at all understood at the beginning of the present century. Some of the most important facts remained unknown until the eighth decade, and even now there are many points requiring further elucidation.

The first six decades of the century were spent in experiments and disputations which served to determine the relations of microorganisms to the phenomena of fermentation and putrefaction, and to settle in the negative the much controverted question in regard to the spontaneous generation of those organisms. In this connection, we must recall the names of several persons prominent in the controversy, or in the events which led up to it: The Hollander Antoon van Leeuwenhoek, "the father of micrography," who lived from 1632 to 1723, was the first to observe minute organisms in fermenting and putrescent liquids by means of the microscope; Needham, 1754, and Spallanzani, about 1760–1770, who were champions pro and con, respectively, of the theory of spontaneous generation; Schultze, 1836, who first asserted that the phenomena of putrefaction and fermentation are induced by the microorganisms ever present in the air and not by spontaneously created organisms; Schwann, 1839, founder of the science of antiseptics, who was another opponent of the theory of spontaneous generation; Liebig, who asserted in 1839 and for many years after that fermentation and putrefaction are not biological phenomena; Schröder and Dusch, 1853, who were inventors of the use of cotton wool for freeing a stream of air from microorganisms; Pasteur, who, beginning the study of the question in response to a prize offered in 1860 by the Paris Academy of Science, demonstrated that any substance whatever may be freed from the germs of putrefaction by a suitably prolonged heating at a sufficiently high temperature, and that the substances so sterilized will maintain that condition indefinitely if the access of organisms from the air is prevented.

This forms the starting point from which has been developed, by a host of workers, our knowledge of the organisms of putrefaction and decay, the changes which they work in the media in which they grow, and the conditions which favor or hinder their growth. It was early discovered that a great number of species of organisms is engaged in the destruction of organic matter in soils and other substances, and that the final products of the process are carbon dioxide, water, and ammonia, with some free nitrogen, and hydrogen in some cases.
It was a well-known fact, however, that ammonia does not accumulate in arable soils in any such quantities as do nitrates, especially under conditions highly favorable for the phenomenon of nitrification, as in the artificial and natural nitrate beds, which were under observation in various parts of the world.

The next point of contention was very naturally the nature of the process by which the nitrogen of ammonia is converted into the form of nitrates under natural conditions. Although Müller, in 1873, and Pasteur, as early as 1862, had suggested the possibility of its being a biological phenomenon or species of fermentation, the change was generally regarded as a purely chemical one, probably wrought by the highly condensed oxygen supposed to exist in the interstices of the soil and of other porous substances. This doctrine was overthrown by the experiments of Schloesing and Müntz (1876), which showed that nitrification is interrupted by the action of antiseptics (chloroform), and that the process can be started again by inoculating the medium with a small amount of fresh soil. These experiments were soon repeated and extended by the discoverers and by Warington, Soyka, and others. An additional proof of the fermentative nature of the process of nitrification was found in the fact that it was stopped by heat when applied in the manner in which it is usually employed for sterilization. During the next thirteen years (1878–1890) many workers took up the study of the nitrifying organisms, and much valuable knowledge relative to their properties was obtained, but the numerous attempts to satisfactorily isolate them and study them apart from the host of other soil organisms were fruitless. Again, an unknown factor rendered futile the efforts of some of our best experimenters, as had been the case in the investigation of the question of the fixation of free nitrogen by agricultural plants, mentioned above. The valuable method of gelatin-plate cultivation invented by Koch for the isolation of bacteria, was found to be inapplicable. Indeed, numerous failures led Frank, as late as 1887, to assert that there could be no organism of nitrification, since no organism separated from the soil was found to possess that property, in spite of the fact that numbers of experimenters had transferred the nitrifying agent from culture to culture, in liquid media, by the usual method of inoculation. It gradually became apparent that the organic matter habitually used in the media employed in plate cultivations was unfavorable to the growth of the nitrifying organisms. Indeed, by repeatedly reducing the proportion of organic matter used in the preparation of liquid media, in which nitrification proceeded satisfactorily, a medium was finally tried which contained no added carbon other than that of the alkaline or earthy carbonates which had been found necessary to neutralize the acid formed by the process, and of which an excess had been found to be detrimental. In this medium the process proceeded with the vigor normal for the liquid media hitherto found most favorable.
Here then was the key to the situation. The organisms of nitrification do not thrive in the presence of an excess of organic matter. In 1890 a new investigator entered the field, a young Russian named Winogradsky. His first triumph was in a satisfactory isolation of the nitric organisms by means of culture plates composed of gelatinized silica, impregnated with nutritive salts and carbonates, but made without any added organic matter whatever. His work upon the subject was temporarily interrupted, but it is now in progress with one or more collaborators.

In addition to the above, there must be mentioned to complete this very brief sketch of the history of the development of the knowledge of the phenomenon of nitrification and of the organisms to which it is due, the work of Warington, Frankland, Jordan and Richards, Godlewski, Burri, Stutzer, Hartleb, Lawes and Gilbert, Dehérain, and others. The results of their joint labors teach us that in order that nitrification may be active in our fields the soil must be well aerated by stirring or by improving its mechanical condition; that a proper degree of moisture must be maintained, and that excessive acidity must be prevented or destroyed by liming. Indeed, this fact explains much of the beneficial action that is known to attend the application of lime to arable land, and strongly argues in favor of a judicious extension of such use. The work of the Division of Chemistry has shown that the nitrifying organisms from soils from all parts of the country are uniformly highly susceptible to the inimical action of an excess of acids in the medium in which they grow.

INJURIOUS SOIL BACTERIA.

We have still to consider a class of soil organisms which are able under certain conditions to destroy a considerable part of the beneficial work of the organisms mentioned above by decomposing the nitrates contained in the soil and returning the nitrogen in them to the atmosphere in the form of free nitrogen. These organisms are normally present in soils and manures and upon crop residues, but only seem to exert their destructive powers in the presence of such an excess of organic matter and under such definite conditions of aeration as seldom obtain in well-tilled soil of good quality and location. Some alarm was occasioned a few years ago by the announcement by German investigators that all stable manures should be sterilized before applying them to the soil, in order to destroy these denitrifying organisms, but this was not supported by subsequent investigation, nor is it generally regarded as good counsel, as the decomposition of the manure is delayed by such a practice.

CARE OF MICROORGANISMS AS NECESSARY AS CARE OF CROPS.

From the above statements the conclusion follows that the farmer must care for the microscopic organisms growing in his soil, manure
pits, and compost heaps, as well as give unceasing attention to the crops which make their appeals directly to his unaided eye. It may be well to add, however, that the best interpretation of the experience hitherto gained is that the farmer should seek to make his soils a highly favorable home for the organisms he wishes to thrive there, rather than attempt to transplant them by "soil inoculation." The rapidity with which most organisms multiply and their extremely wide distribution show that they are sure to follow their favorite food and other conditions of growth sooner or later. It may of course be true in many cases that time will be saved by inoculating the soil or seed with the organism desired.

The same principle should govern endeavors to eliminate organisms which are found to be unfavorable.

**AGRICULTURAL CHEMICAL TECHNOLOGY.**

Chemistry has done much to promote the progress of agriculture in the line of chemical technology. Good markets for farm products, as has already been stated, are essential to progress and prosperity. Many of the raw materials produced upon the farm enter at once into manufacture, and their value on the market largely depends upon the demand for manufacturing purposes. The principal agricultural chemical industries are starch and glucose manufacture, sugar manufacture, wine making, brewing, distilling, tanning, and fertilizer manufacture. In all these industries chemistry plays a leading part.

**STARCH MANUFACTURE.**

In the making of starch, chemical science has brought the utilization of the by-products to such perfection that the value of these products alone more than pays the whole expense of manufacture. This fact enables the producers to put the starch upon the market at a price far below what would be possible if chemistry had not come to the aid of the industry. Thus, a vastly greater demand for the raw materials of which starch is made is secured. In Europe potatoes are the principal source of starch, while in the United States indian corn is practically the sole material of economic importance used for this purpose. It is true that in Maine there is a large industry devoted to the manufacture of starch from potatoes, and a few small factories are found in other parts of the country, notably Michigan. The total quantity of starch, however, made from potatoes is extremely small when compared with the product from indian corn. In the manufacture of starch from indian corn chemical problems of the greatest importance are involved. The presence of nitrogenous matter in starch is undesirable, and the separation of the starch in the indian corn from the nitrogenous materials is of the utmost consequence to successful manufacture. By chemical processes, joined with mechanical ingenuity, this separation is now effected in such a way as to
leave the nitrogenous matters in a state suitable for animal food. Thus, while, on the one hand, the starch of the Indian corn is obtained in a practically pure state, on the other, the waste products are recovered in the form of cattle food of high nutritive value. Again, the germs of Indian corn are composed chiefly of oil and protein matter. These are also separated in the process of manufacture, the oil is expressed, and the residue forms a food extremely rich in protein, and valuable both as a cattle food and as a fertilizer. The oil itself, by chemical processes, is prepared for various purposes, among others for the manufacture of a material resembling rubber. All these results have been accomplished by the application in a practical way of the principles derived from chemical investigations.

**GLUCOSE MANUFACTURE.**

The manufacture of glucose from starch is a chemical process pure and simple. In chemical studies it was early discovered that when starch was submitted to the action of certain ferments and acids it was converted into sugar. This is the principle upon which the manufacture of glucose rests. Formerly sulphuric acid was chiefly employed in producing this hydrolysis. At the present time, however, hydrochloric acid is more commonly used. The starch in the form of a thin paste is subjected to the action of dilute hydrochloric acid under pressure. In a few moments the starch is converted into a mixture of dextrin and dextrose, in which condition it is used for the manufacture of the liquid material known in commerce as "glucose." A longer treatment with hydrochloric acid converts the dextrin into dextrose, and this is the form in which it is used in the manufacture of a solid sugar known as "grape sugar." After the conversion is completed, the hydrochloric acid is neutralized with soda, forming a little common salt, which does not interfere with the use of the glucose and grape sugar for the purposes for which they are used.

**SUGAR MANUFACTURE.**

In sugar manufacture we see even a more important utilization of chemical knowledge. Especially is this true of the beet-sugar industry. By means of chemical studies the sugar beet has been developed from the common garden beet, containing only 5 or 6 per cent of sugar, to its present condition of a root containing from 12 to 16 per cent. This great improvement has been secured solely by the aid of chemical science conjoined with the highest skill in practical agriculture. In the process of manufacture, however, chemical science has been even more successful. Beet juices, on account of their composition, present greater difficulties in manufacture than the juice of sugar cane. Without the aid of chemical science the present status of beet-sugar manufacture would have been impossible of attainment. Thus, through the exertions of chemistry, an industry has been established
which has made a profound impress upon agriculture in general. Regions which are devoted to beet culture are everywhere known as those in which the highest form of scientific agriculture is practiced. Around the beet factory are naturally grouped vast dairy interests, where the cattle are fed upon the pulp from the diffusion batteries. The culture of beets implies the application of those principles of agricultural chemistry which secure an increase of the soil fertility. Every beet field, therefore, becomes a practical experiment station, where the best forms of agriculture are taught. All crops receive the benefits of this high culture, and thus, in these applications of the principles of practical agricultural chemistry, the general welfare of the agricultural interests of the community is secured. Perhaps there is no other instance in chemical technology where the application of scientific principles has proved of such signal advantage to the progress of agriculture.

WINE MAKING.

Wine making rests also largely upon chemical principles. In grapes we find large quantities of sugar combined with organic acids, of which tartaric acid is the chief, coloring matters, tannic principles, etc. The production of wine of fine flavor consists in securing the fermentation of the sugars of this mixture with appropriate ferments and under carefully controlled conditions of temperature. Only through the most careful chemical control are the most favorable conditions maintained. Consciously or unconsciously, the wine maker is a practical chemist, and under the influence of modern research the scientific principles of wine making are very much more firmly established and more easily practiced than they were before the conditions under which wine is produced were thoroughly understood. In wine making chemistry also exercises an important function in the utilization of the by-products. The tartaric acid present in grapes is very valuable in commerce, forming, in combination with potash, the well-known substance cream of tartar, which is so extensively employed in the manufacture of baking powders and for other purposes. By the application of the principles of chemical technology to the residues of the wine press and to the incrustations which form upon the vats the cream of tartar of commerce is secured.

BREWING.

Brewing is also largely a chemical science. The chief problem in the brewing industry is that of fermentation, and the development of fermentation has been due solely to the researches of chemists. In the brewing industry the first object is to convert the starch of the cereal into maltose and subsequently to change the maltose into alcohol by fermentation with yeast. By the researches of physiological chemists, it was discovered that the active principle in the conversion of starch into sugar is an enzymic ferment commonly called diastase,
which is developed in barley by germination. This ferment rapidly converts starch into maltose, the conversion often taking place within a few minutes. By the researches of Pasteur and other distinguished chemists, the method of producing pure cultures of yeast was established. It is important, in order to secure a fine flavor to the finished product, that the ferment be as pure as possible. It is thus seen that in the chief problems which underlie the brewing industry chemistry takes a leading part.

DISTILLING.

The industry devoted to the manufacture of alcohol, whisky, and brandy is also chiefly of a chemical nature. The distilling industry naturally follows after the brewing industry. The manufacture of alcohol from starch may be described as the same in both industries. After the alcohol is formed it is separated from the mash by distillation. In spite, however, of the greatest care in the selection of yeasts, several varieties of alcohol as well as of organic acids are formed during the process of fermentation. After the distillation is finished, therefore, the separation of common alcohol from the impurities with which it is naturally mixed becomes a difficult chemical problem. The progress which has been made in this line, however, has been so great as to render the production of pure alcohol on a commercial scale an industrial proceeding of great magnitude. Chemical principles also of the utmost importance underlie the production of whisky and brandy, due to the elimination of objectionable alcohols by means of oxidations produced by storage under proper conditions of temperature and in suitable vessels. The whole process of aging a whisky or brandy or wine rests exclusively upon the proper conduct and control of the chemical reactions which take place.

TANNING.

The hides (at least indirectly) and also the principal part of the materials used in the process of tanning are products of the soil. Chemical technology has shown that in the process of tanning the gelatinous matters of which hides are composed are impregnated with tannic principles in such a way as to change their nature, rendering them insoluble in hot or cold water, resistant to atmospheric influences, flexible, and lasting. All these conditions are obtained by strictly chemical processes which have been carefully worked out. The relations of gelatin to tannin have been made the subject of the most careful chemical research. In like manner the utilization of the tannin-producing forests has been rendered much more economical. Formerly only the bark of the oak, the hemlock, and the chestnut was employed, but chemical science has shown that mixed with the fiber of the wood itself are tanning properties of a high value. In canaigre and other plants, chemical research has discovered sources of tannin that will take the place of tan bark, in the quest of which vast forests have been destroyed. Chemical technology has also taught the
method of extracting from the bark and the wood their active principles, thus enabling dealers to transport the tannic principles in a condensed state and at a greatly reduced cost for freights. Almost all the great tanning industries of the country at the present time employ skilled chemists, and in many instances these chemists are directors of the factories.

FERTILIZER MANUFACTURE.

Perhaps chemical technology has rendered agriculture no other service so valuable as that which it has given in the development of the fertilizing industries of the world. The vast deposits of plant foods which occur in South America in the form of nitrate of soda, in Germany in the form of various combinations of potash, and in this country in deposits of mineral phosphates are made useful to agriculture only through the intervention of chemical technology. The earths saturated with nitrates in South America are treated chemically and the fertilizing principle obtained in a condensed form, making their economic transportation possible. The compounds of potash obtained in the mines near Stassfurt are subjected to chemical treatment, whereby the potash salts are concentrated and obtained chiefly in the form of sulphate and chlorid. The vast deposits of mineral phosphates furnish abundant materials which are subjected to treatment chiefly with sulphuric acid, and thus phosphoric acid is secured in a soluble form suitable for absorption by the growing plant. The wastes and offal of the cattle pens and abattoirs are collected and treated chemically and the nitrogenous and other fertilizing materials they contain secured in merchantable shape. Bones are subjected to mechanical and chemical treatment in order to render their phosphoric acid quickly soluble. Chemical technology has even established an intimate bond of union between agriculture and metallurgy. Iron ores that a few years ago were totally unfit for use by reason of the large amount of phosphorus they contained are now converted into the finest steel by new chemical processes which at the same time secure the phosphoric acid in the form of basic phosphatic slags, considered one of the most valuable phosphatic manures in use.

RELATION OF CHEMICAL TECHNOLOGY TO GENERAL AGRICULTURE.

In the above ways, the science of chemistry has offered to agriculture stores of plant food which a few years ago were totally inaccessible and useless. These stores are practically inexhaustible, since chemistry has shown that the atoms of plant food which are thus employed in the nutrition of the plant return after their cycle of life to the mineral state, only again to be made available for human nutrition. Chemistry in its relations to the technology of fertilizing materials has pointed out the way for indefinitely increasing the fertility of the soil and of laying forever the specter of starvation, which has so often been raised to threaten the future of mankind.
It is thus seen that chemical technology, while not directly concerned with the tillage of the fields, has done a wonderful work in establishing agriculture as a scientific profession and assuring its future against the principal dangers which menace it.

**THE DEBT OF AGRICULTURE TO CHEMISTRY.**

The foregoing sketch of the relations of chemical research to the progress of agriculture during the past hundred years presents an outline view of the status of this industry and its debt to science at the close of the nineteenth century. The true composition of the soil and its relations to plant growth are now known. The methods of utilizing plant food and of conserving it for the coming years have been fully established. The principles of plant growth and the chemical changes attending it are understood. The laws of animal nutrition have been experimentally elucidated, and by their application great economy in the use of nutrients is effected. The methods whereby organic nitrogen is prepared for plant food have been revealed, and some of the ways in which atmospheric nitrogen enters into organic combination are marked out. The application of the principles of chemical technology to the elaboration of raw agricultural products has added a new value to the fruits of the farm, opened up new avenues of prosperity, and developed new staple crops.

The closing of the century sees in this country an endowment for agricultural research which excites the admiration of the whole civilized world, and a study of the personnel of the scientific corps shows that fully half the amount expended for strictly scientific investigations has been for chemical studies. We find chemistry intimately associated with nearly every line of agricultural progress and pointing the way to still greater advancement.

When we contrast the condition of agricultural chemical knowledge which now obtains with the nebulous, empirical, and illogical theories which characterized it one hundred years ago, the distance we have traversed seems indeed long; but we should not forget that we are still only on the threshold of knowledge. The achievements of the next century ought to surpass those which the past one looks upon with pride.

To him who writes the story of the progress of agriculture as influenced by chemical research during the twentieth century may come a feeling of pity for the ignorance which now surrounds us; but he will at least accord to our workers the merit of being emancipated from the slavery of opinion and the worship of authority. He will certainly say they were patient, industrious, and truth loving. To the leaders of progress for the next century we commit our unfinished work, confident of their integrity and hopeful of the good which they will bring to mankind.